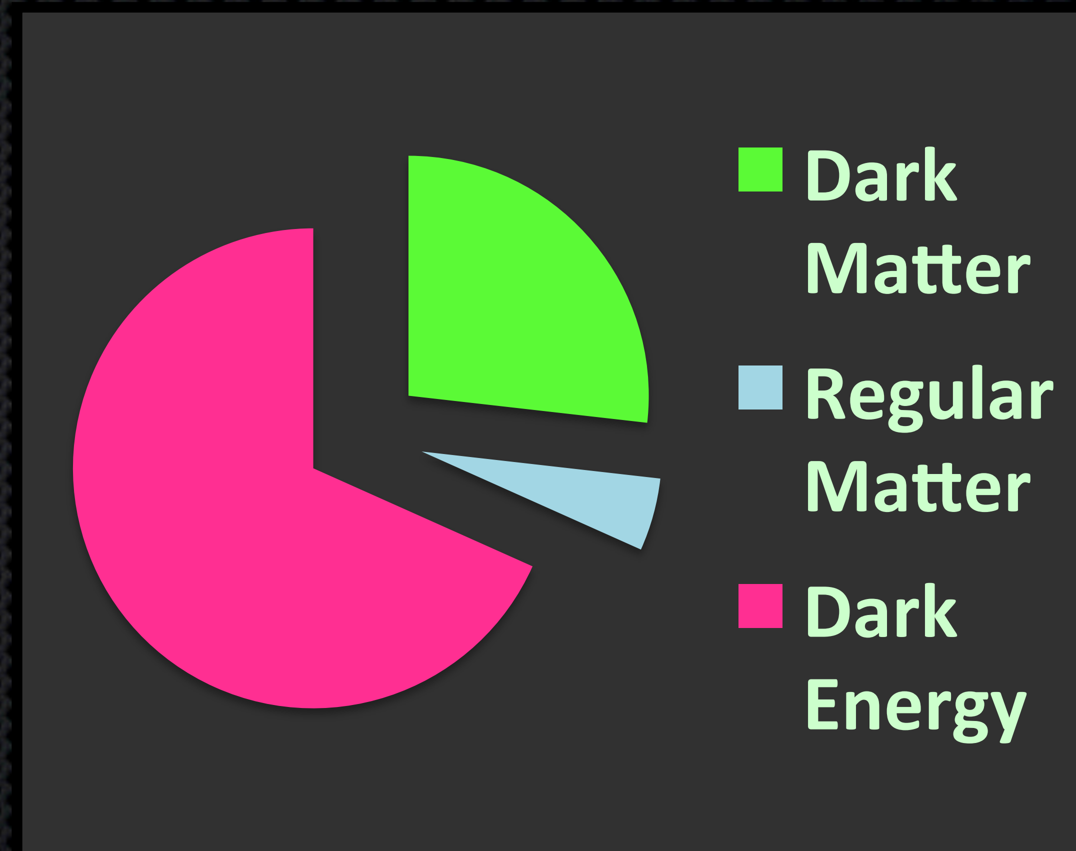
Low Mass WIMP Searches with SuperCDMS

Ritoban Basu Thakur
Fermilab / UIUC

New Perspectives ’13
Fermilab

On behalf of the SuperCDMS collaboration

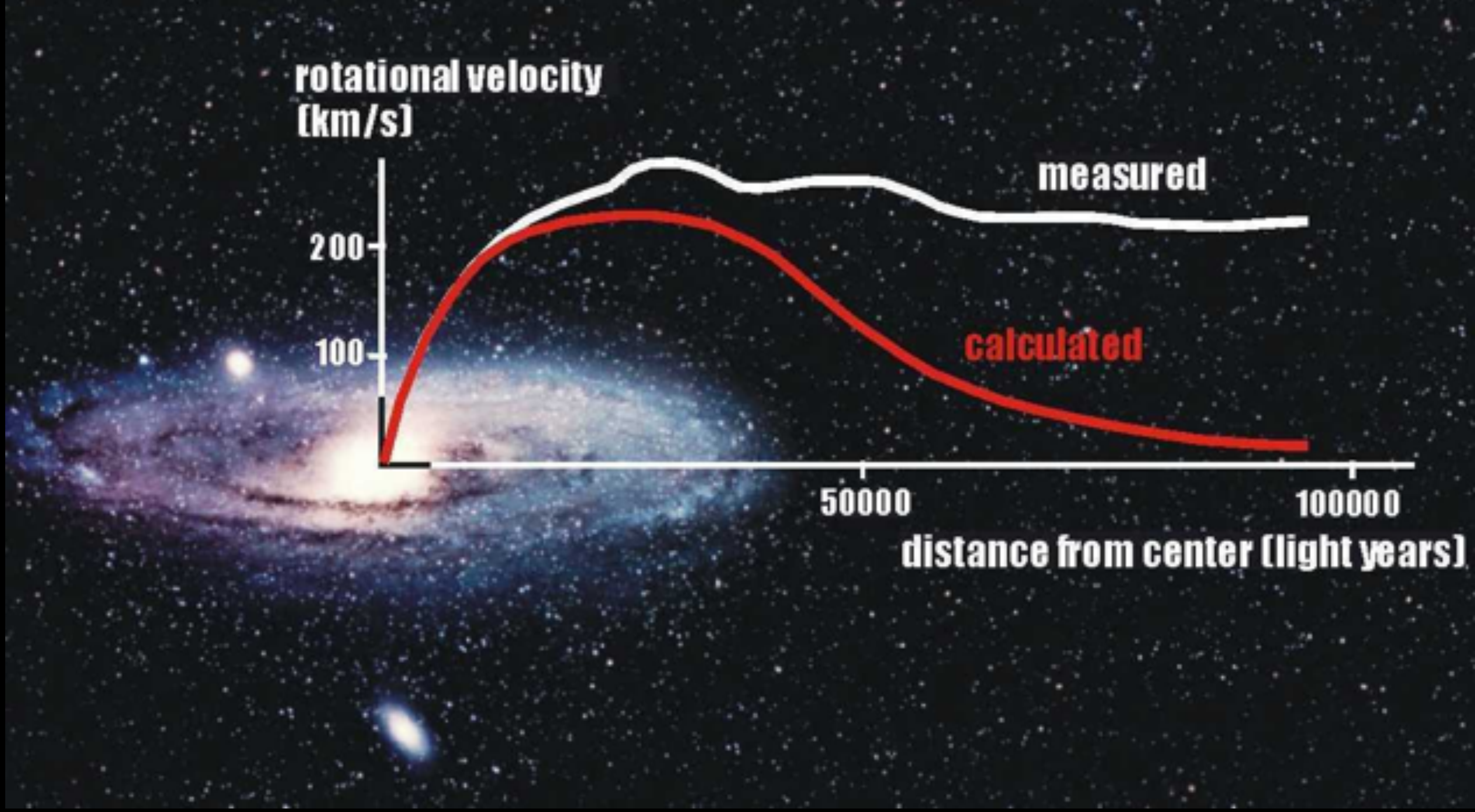
Dark Stuff

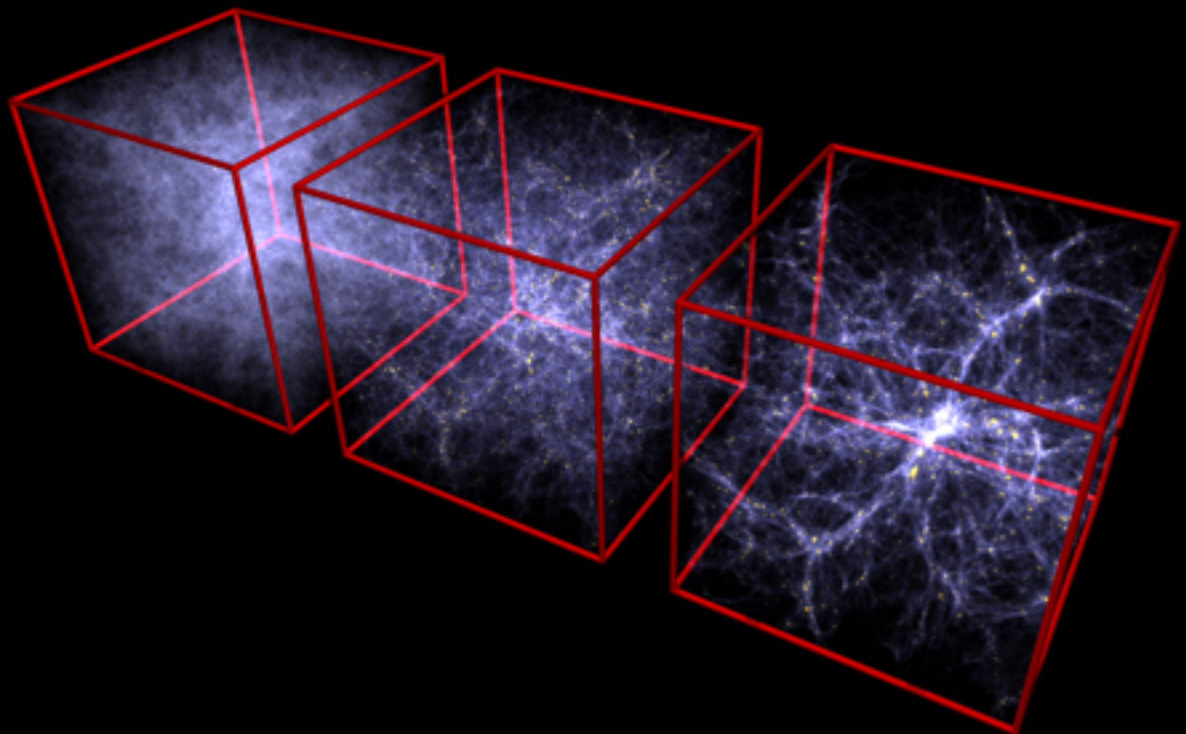


And it's more plentiful than the "truths" of the Standard Model

Dark Matter:

Dark Matter Ring in Galaxy Cluster Cl 0024+17 (ZwCl 0024+1652)
Hubble Space Telescope • ACS/WFC

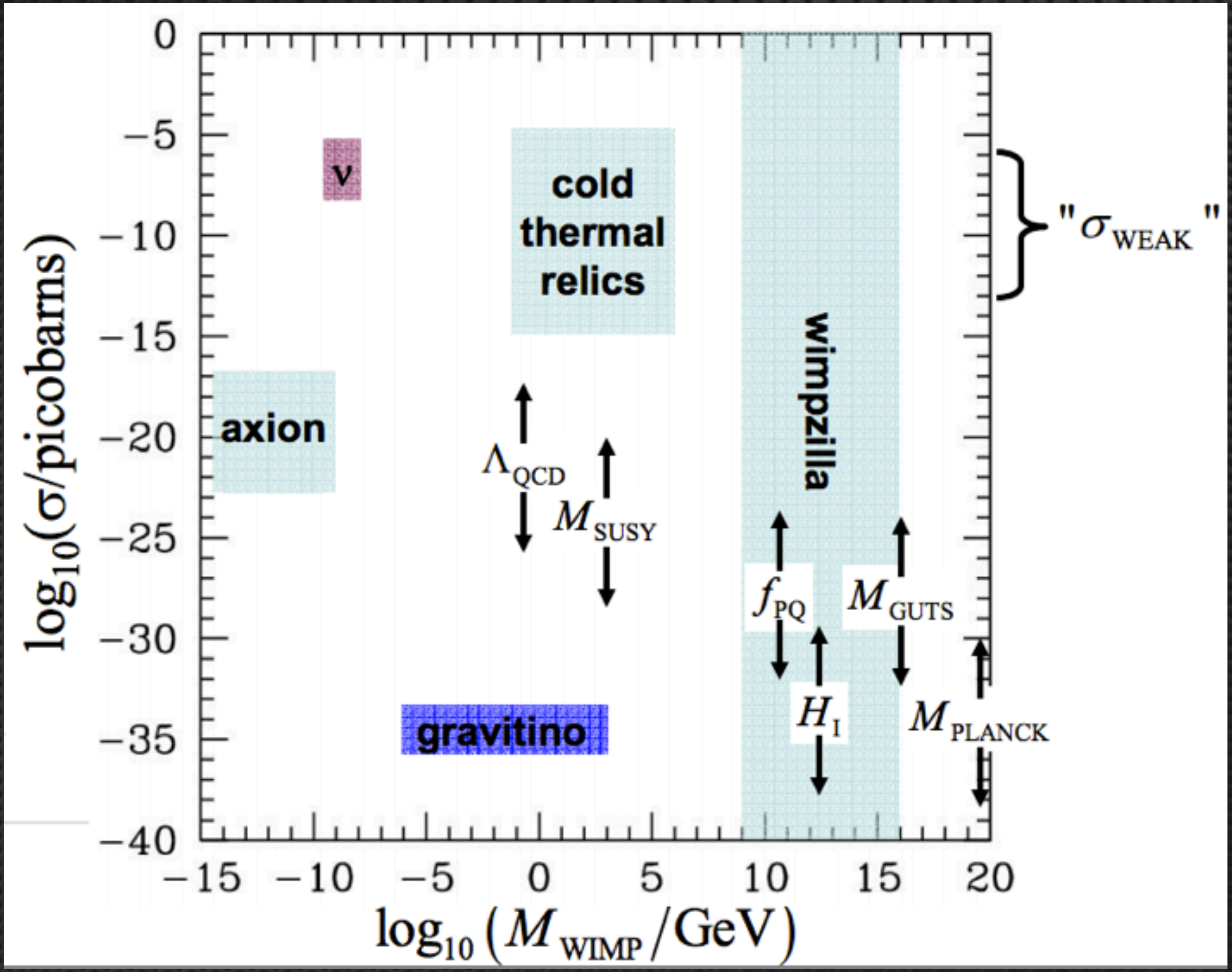




- Plethora of observational evidence
- Simulations are in good agreement
- Necessary for structure formation
- No direct measurements !

Theoretical Landscape:

What can Dark Matter be ?



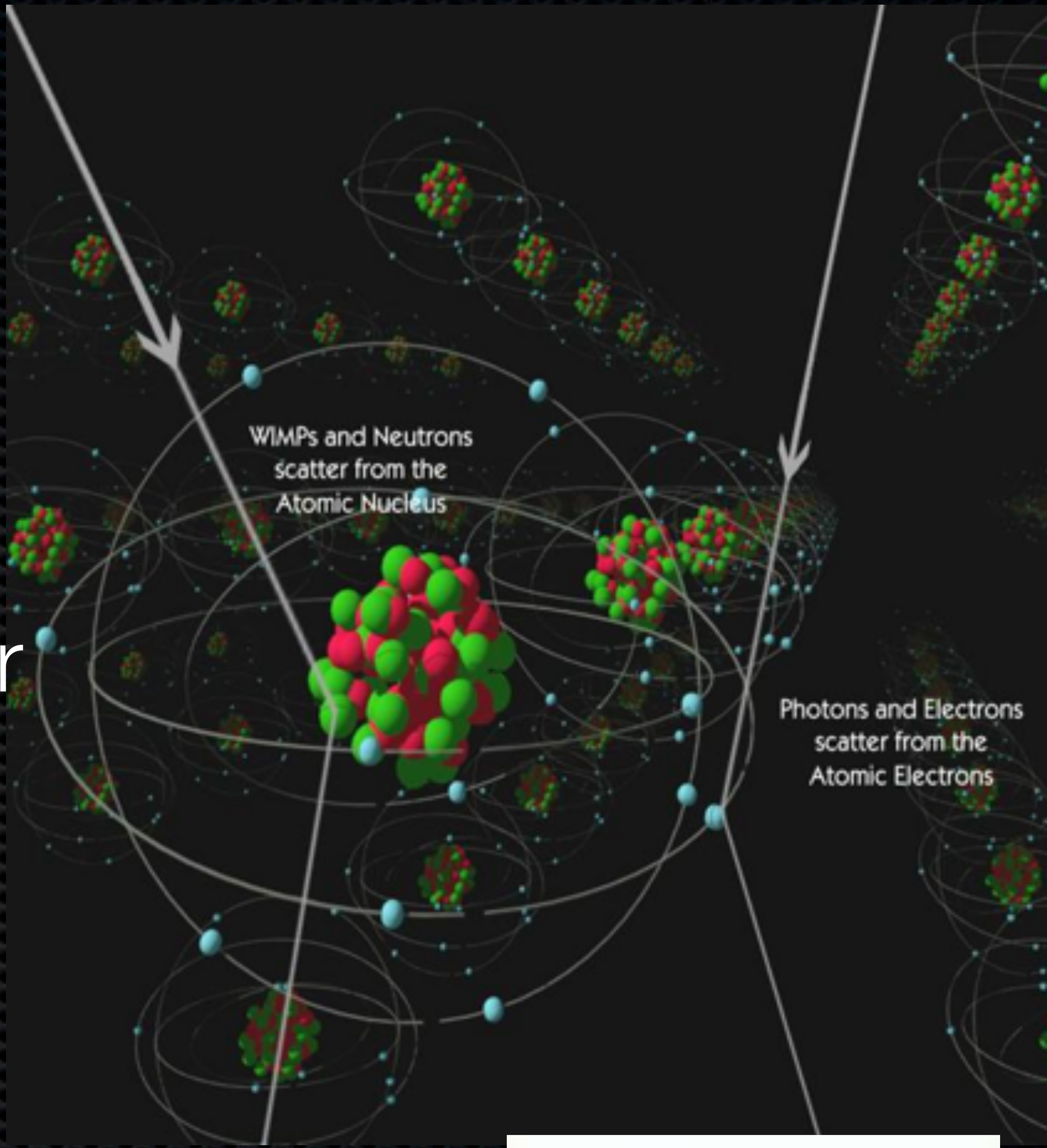
Favored candidate:

- Popular candidates are WIMPs
- WIMPS: stable, neutral, weakly interacting massive particles
- Originally motivated by weak freeze out
- Neutralinos from SUSY
- Current theoretical / observational limits:

$$10^3\mathrm{GeV} \gtrsim m_\chi \gtrsim 1\mathrm{GeV}$$

$$\sigma_{\chi,n} < 10^{-43}\mathrm{cm}^2$$

Direct Detection:



- Expected Exponential spectrum
- Rate driven by cross-section, astrophysical distributions and nuclear form factors

Rates:

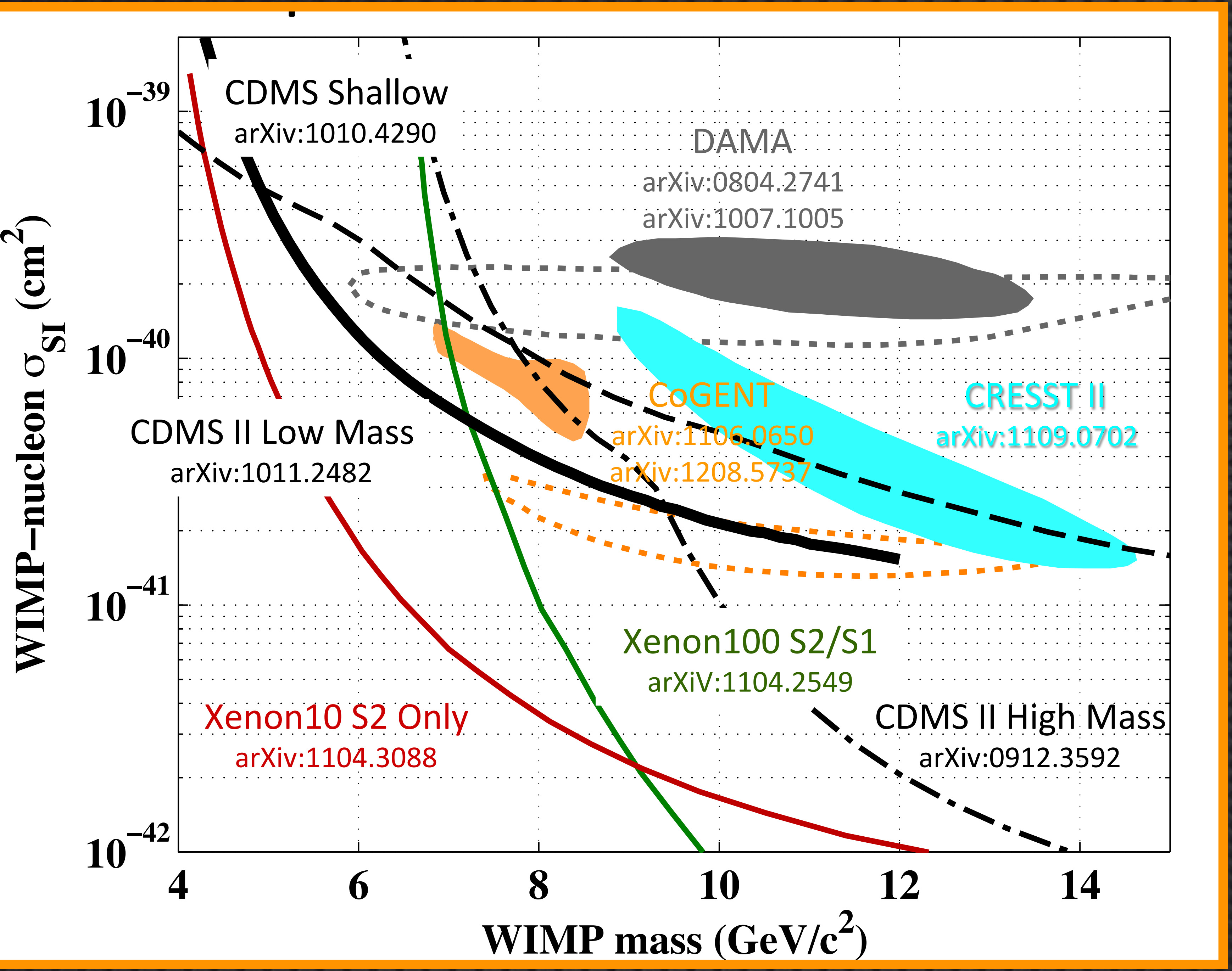
Expected WIMP rates < 10^{-2} interactions/kg/year

So detector masses several kg to tons, and super long (years) runtimes !

C.f. A dozen bananas in 1 day has > 10^6 decays

Major investment in shielding and purity

Experimental Landscape:



Many experiments are in contention

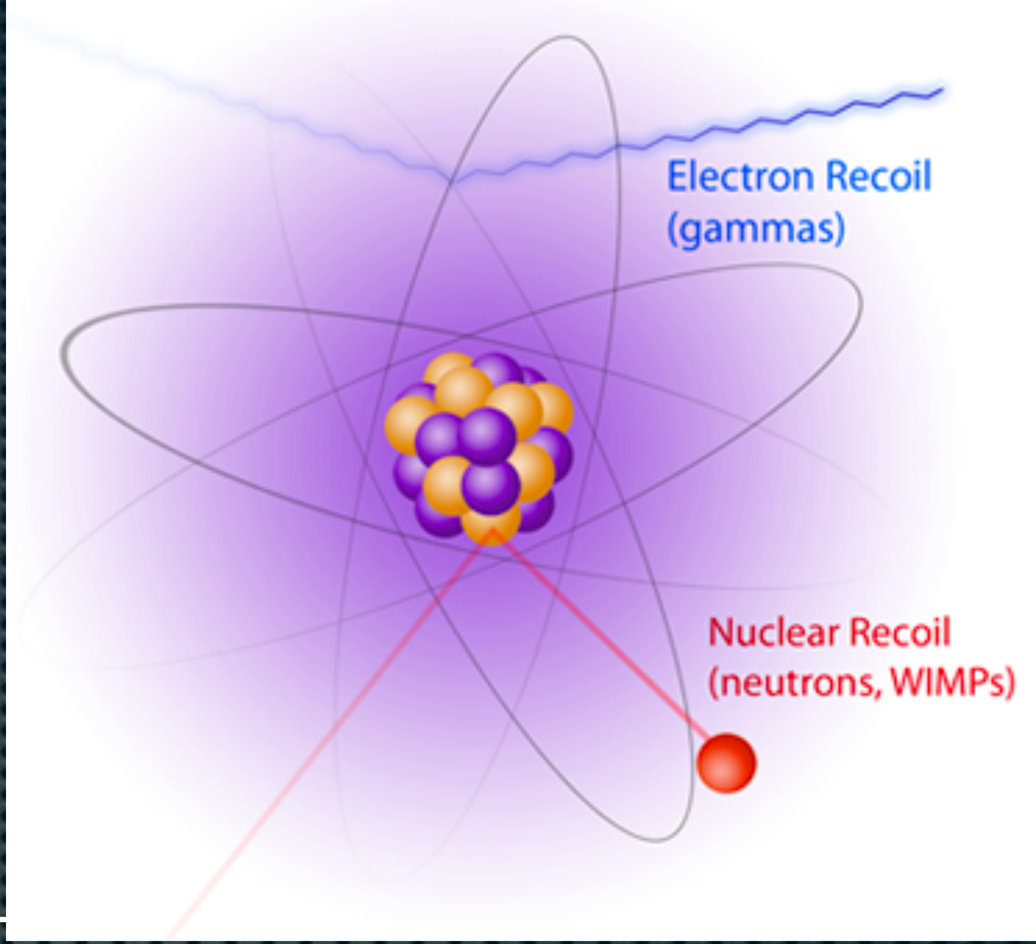
Some experiments report excesses at low energies

Others have limits which are in disagreement

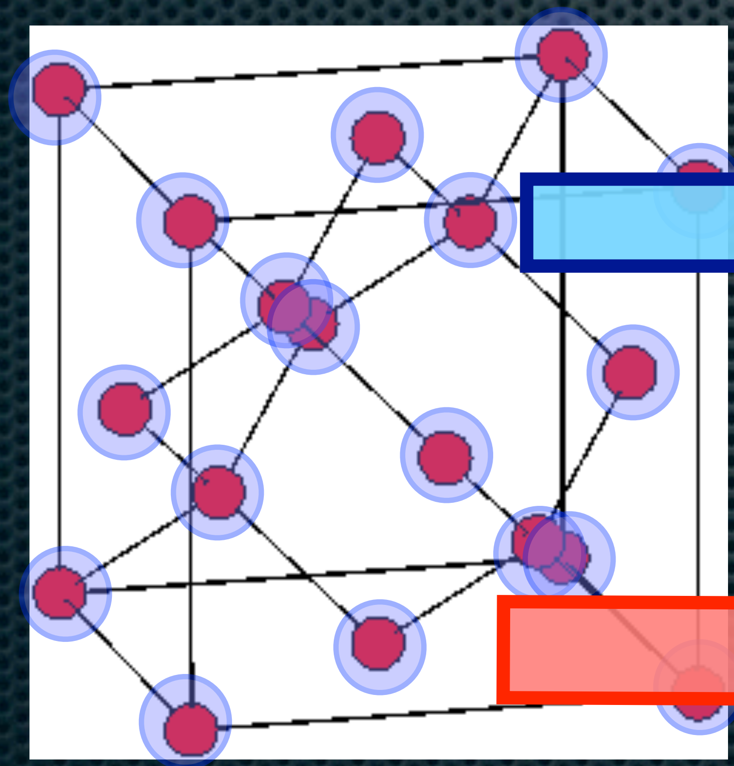
If these are signals, then Dark Matter might be Light WIMPs

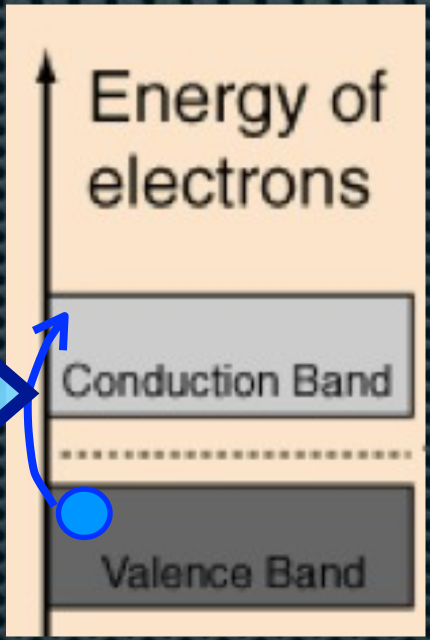
CDMS: detector physics

WIMPs (neutral and massive) will interact more with nuclei than e's

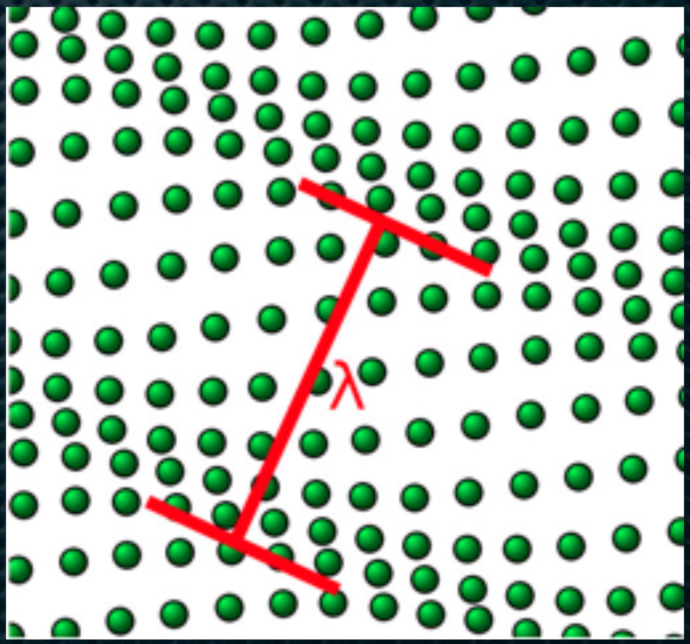


Lattice

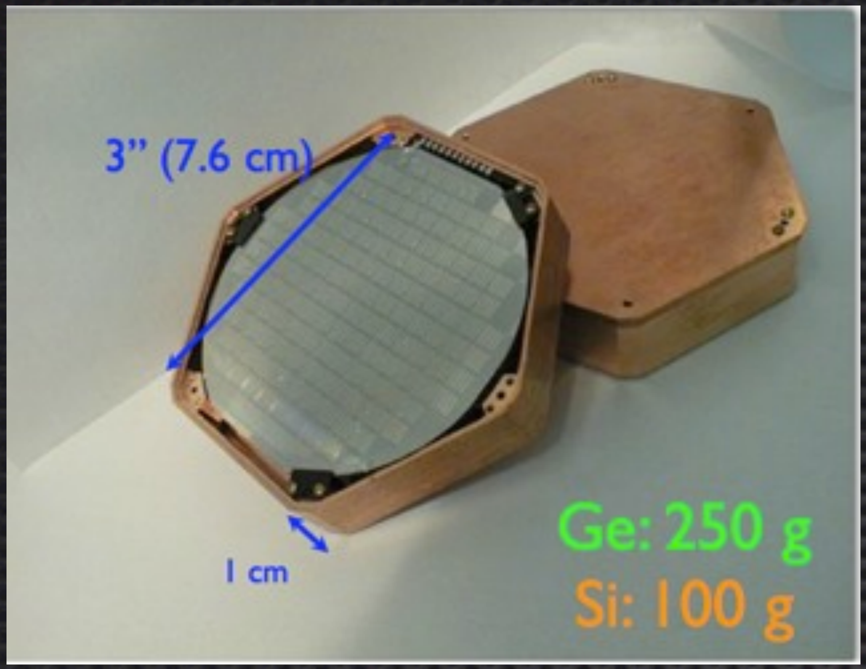


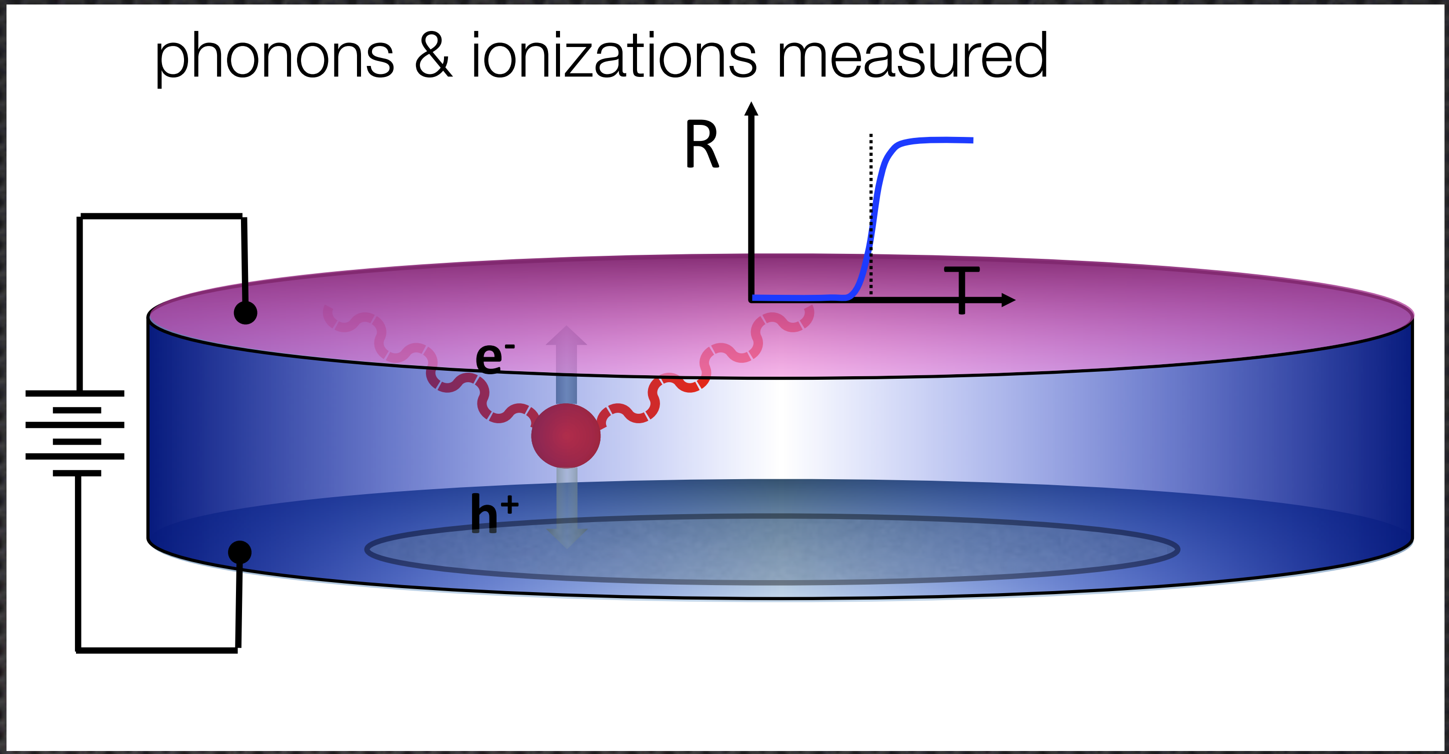


Interaction w/ lattice nuclei -> phonons i.e heat



Recent addition from CDMS II -Si





CDMS II used Ge and Si detectors at Soudan

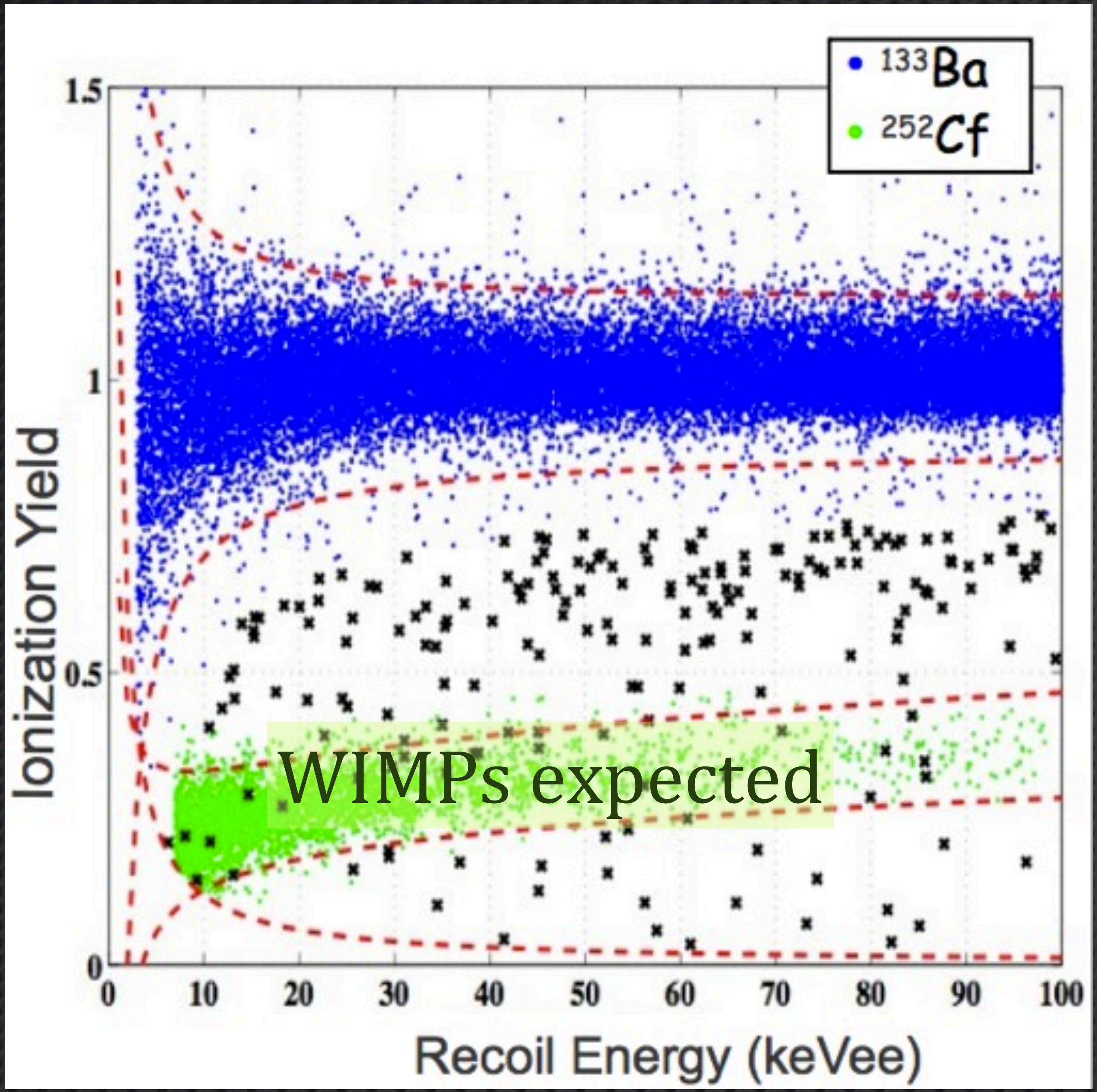
Ge detectors showed 2 candidates in 2010 analysis (arXiv:0912.3592)

Low threshold limits from Ge 2011 (arXiv:1011.2482v3)

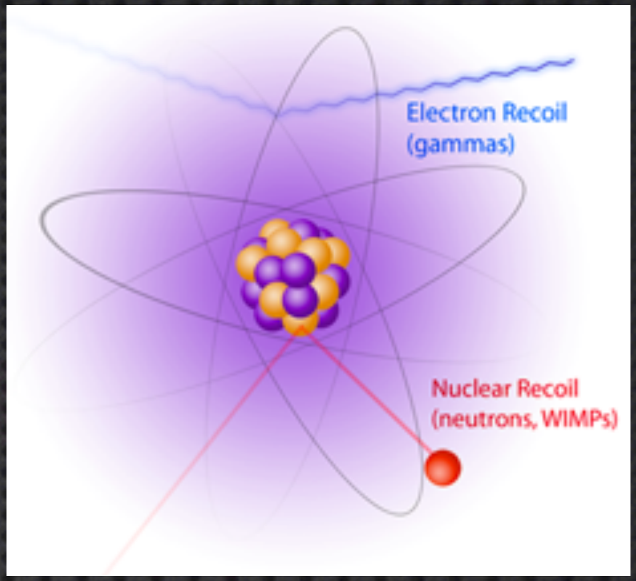
Interesting results recently published from 8 Si detectors with 140.23 kg-day exposure. (arXiv:1304.4279)

Si has better kinematic matching to light WIMPs

CDMS II:
Yield Discrimination



$$\text{Yield} = \frac{Ionization}{Phonon}$$



Yield is our primary discriminator between Electron and Nuclear Recoils

CDMS II had 1:10^4 ER rejection in Yield.

However, some ER points droop into the NR band !

→ Surface Events

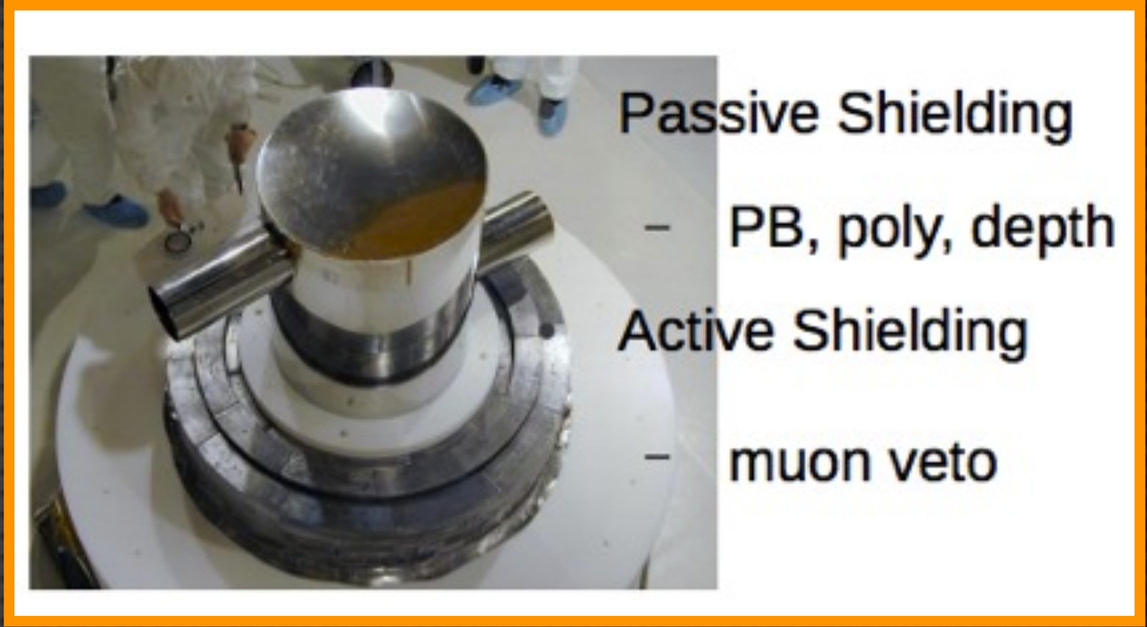
Expectations of the Si background

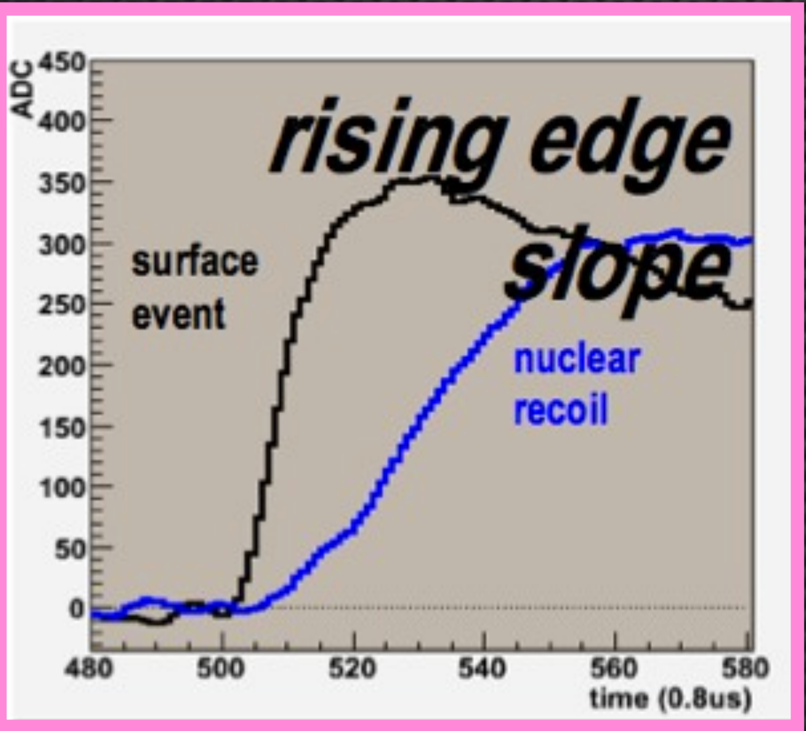
Neutrons

Active veto rejects cosmogenic neutrons.

Passive shielding stops radiogenic neutrons

Expected background < 0.13





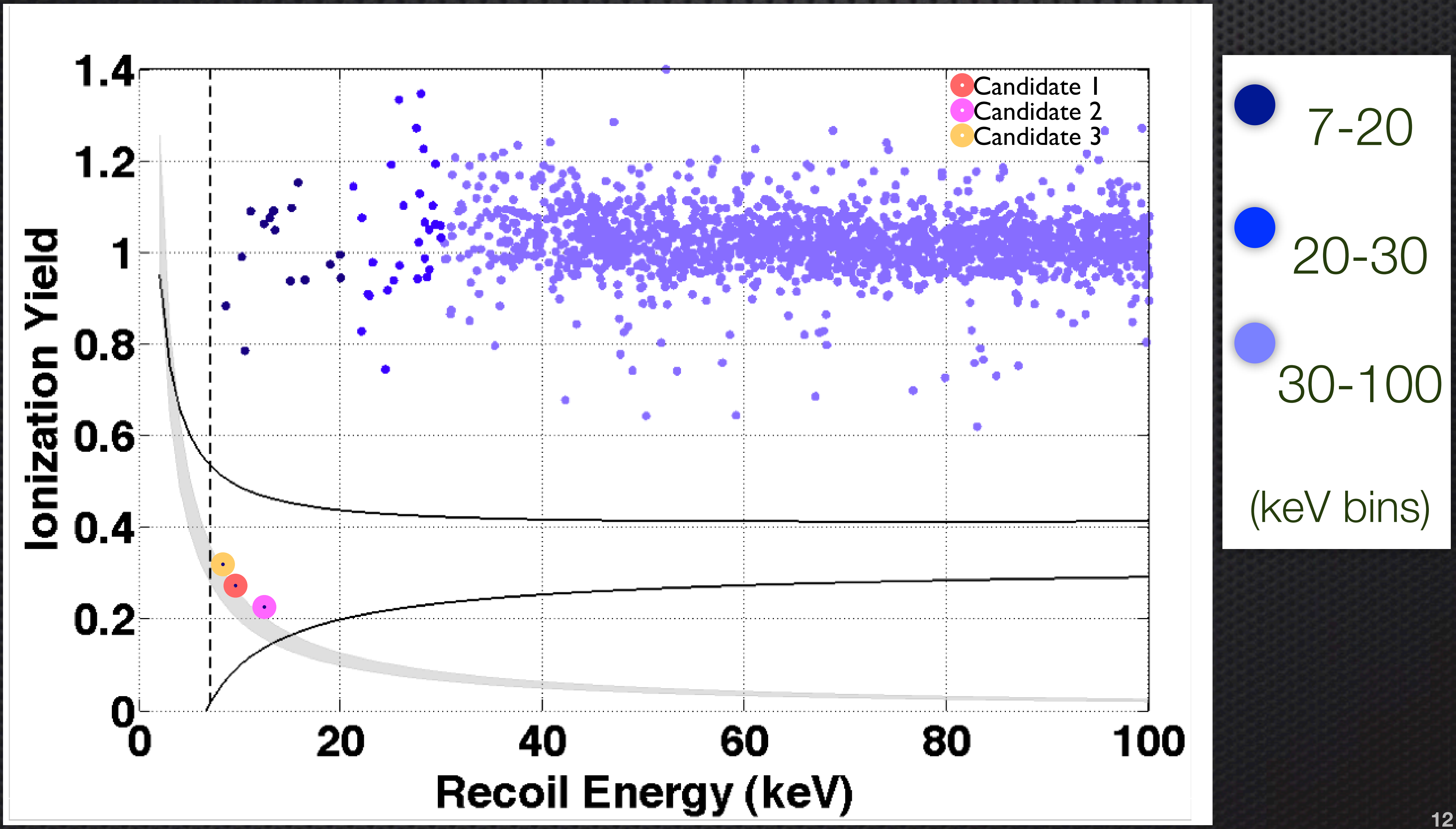
Surface events

They are rejected by timing cuts

Expected ~ 0.47

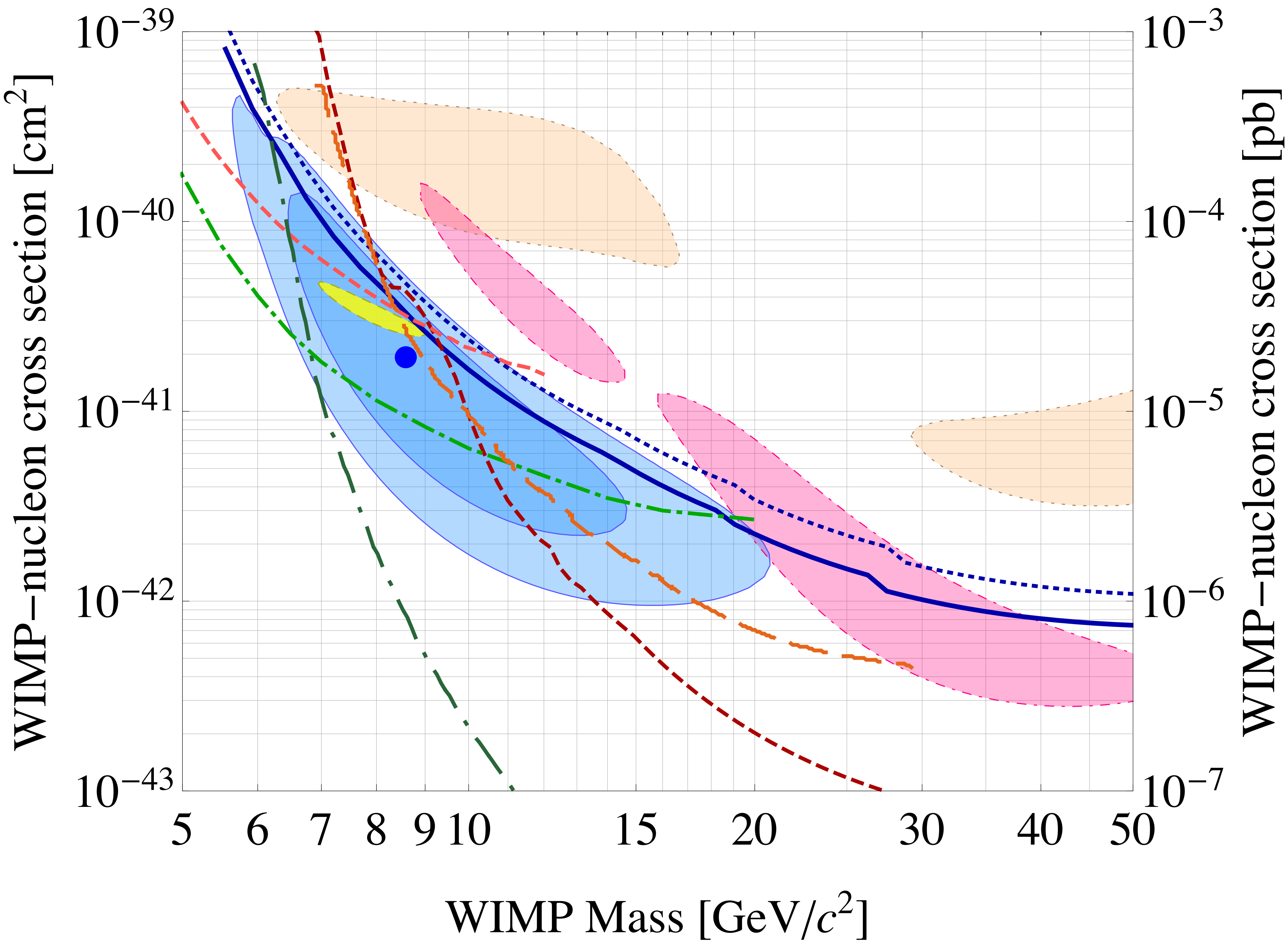
Results from the Si analysis

Post unblinding and timing cuts, stability and multiples check reveal 3 good candidates



Light WIMP parameter space today

Likelihood test favor WIMP+ background at 3 σ



Low thresh. Ge
Regular Ge
EDELWEISS low thresh.
XENON 100
XENON S2
Combined Si
Limit from this
CoGeNT
CRESST
DAMA/LIBRA

Interlude

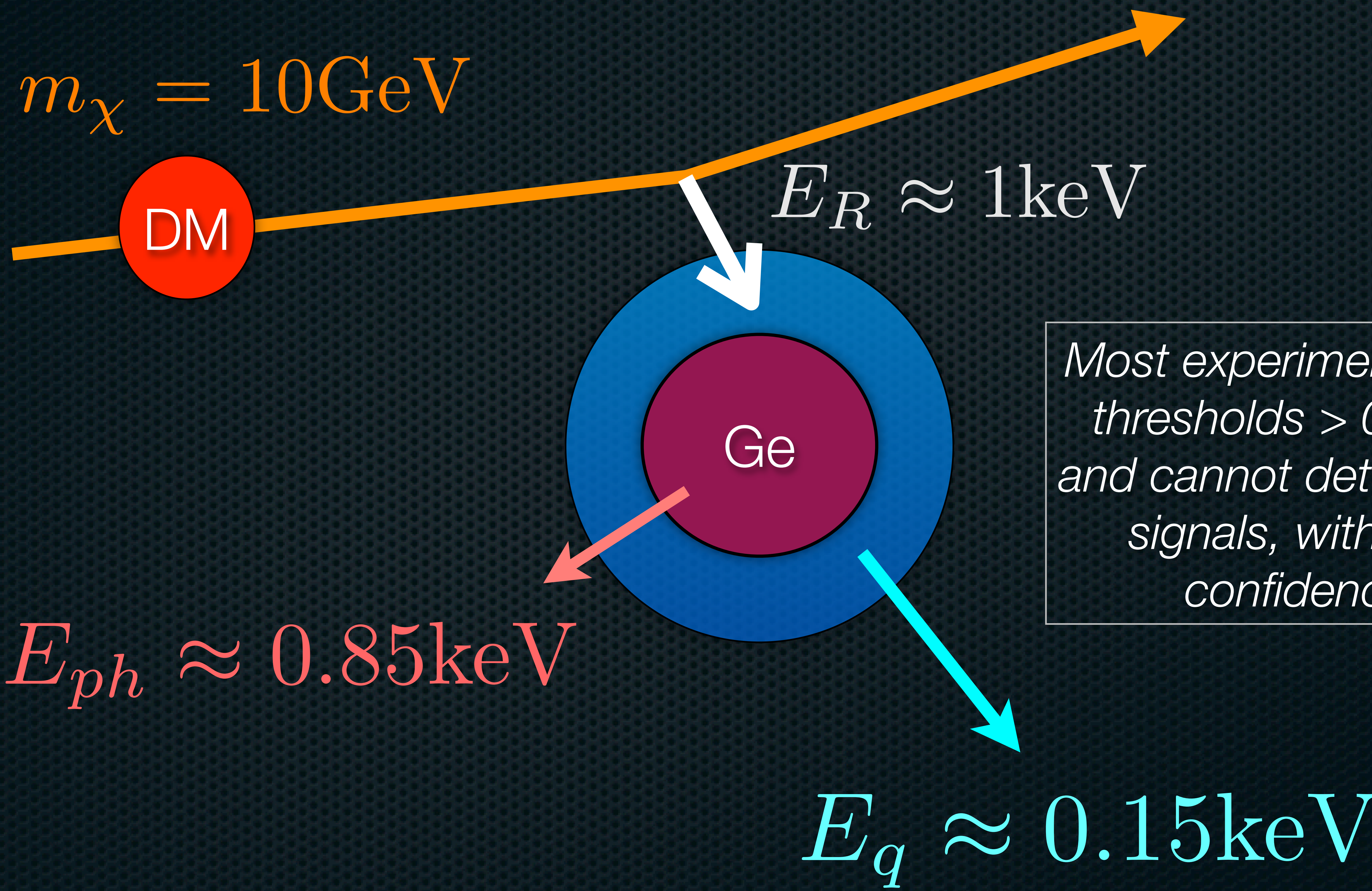
The Low Mass WIMP space has become more interesting.

We must design experiments clearly probing $m_{WIMP} < 10$ GeV/c^2 space.

Thresholds must be << 1 keV.

With this in mind ...

Challenges at low energies



Most experiments have thresholds > 0.5 keV and cannot detect such signals, with high confidence.

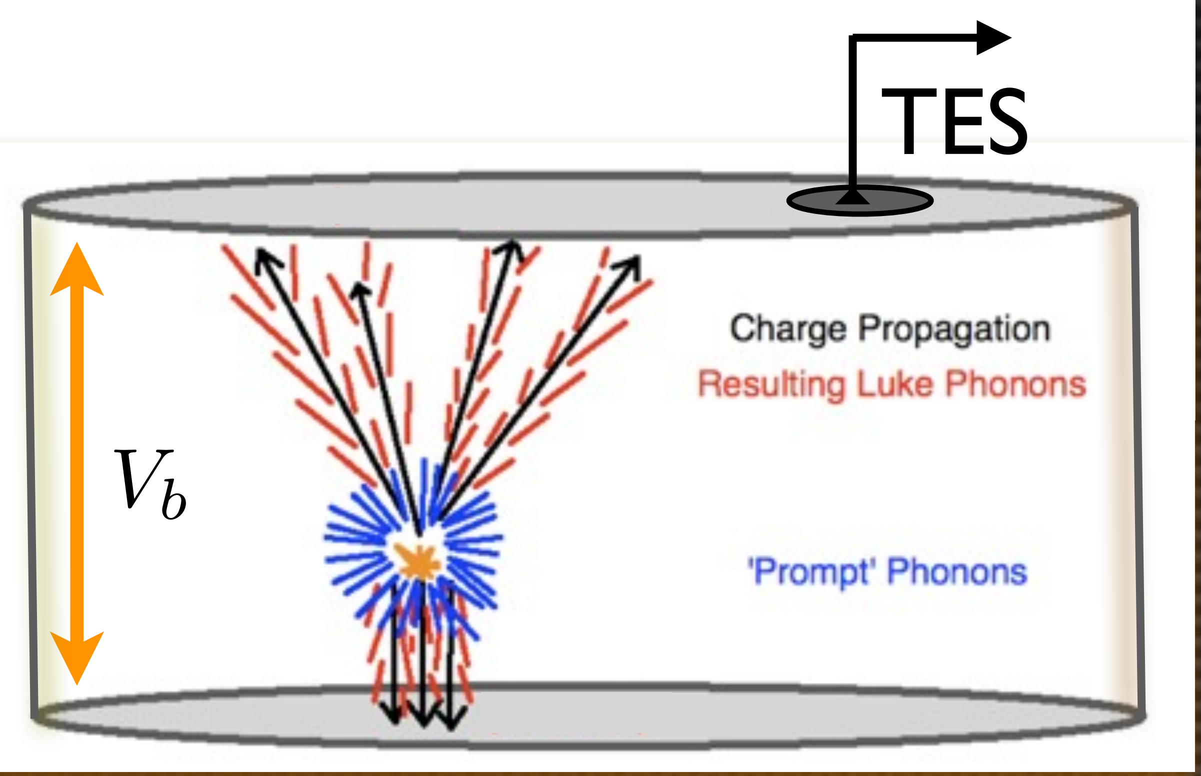
CDMS – low ionization threshold experiment

Ionization only experiment

Utilizes novel electron phonon physics

Potentially 85 eVee threshold

Luke phonons: lower thresholds



$$E_{Luke} = N_{e/h} \times eV_b$$

Bias voltage accelerates electrons / holes

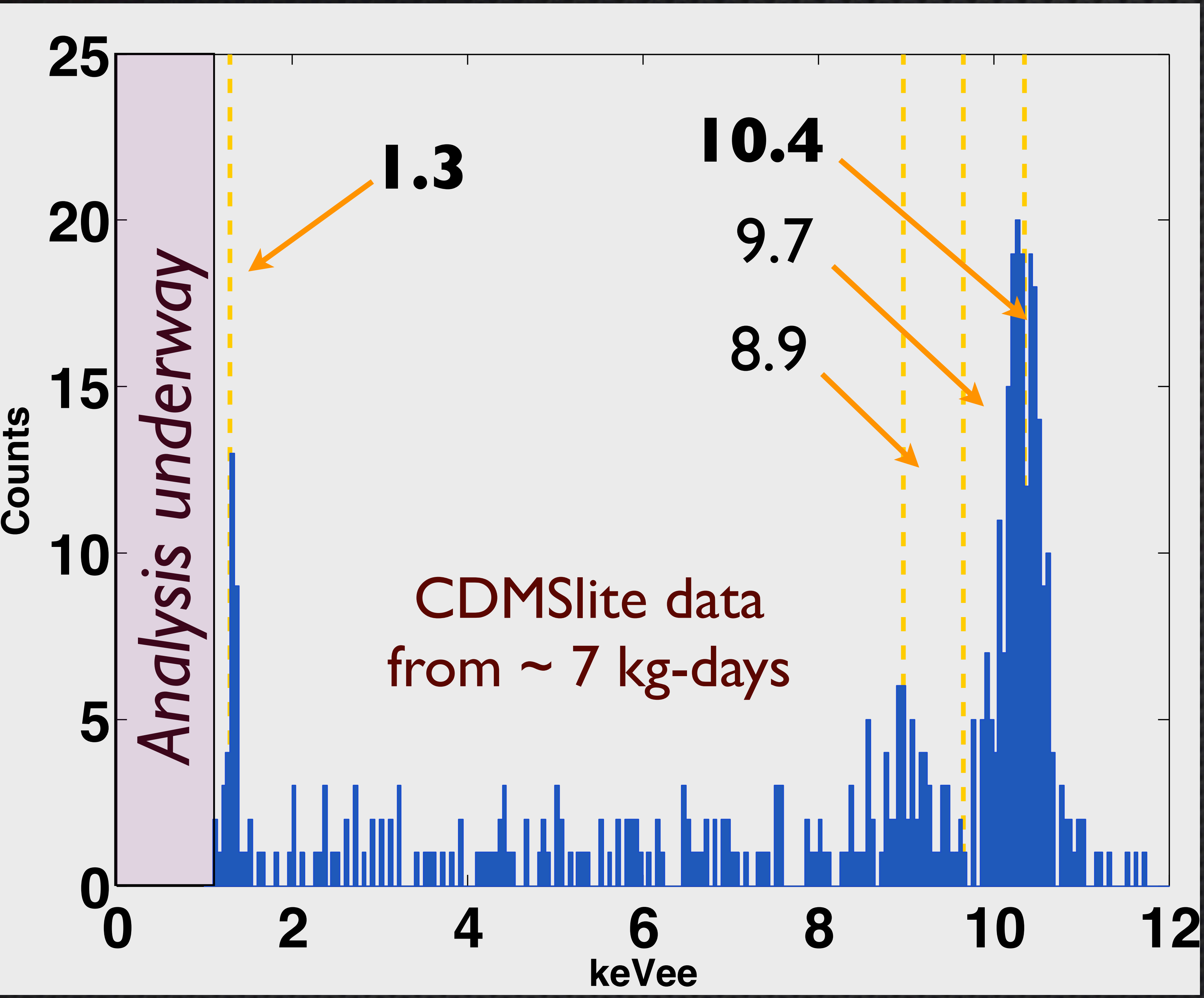
e/h have "terminal velocity"

This "excess energy" is radiated as Luke phonons

Noise ~ constant with V_b

Small $N_{e/h}$ → increase V_b →
Clear detection of low energy recoils

Activation lines: clear resolution

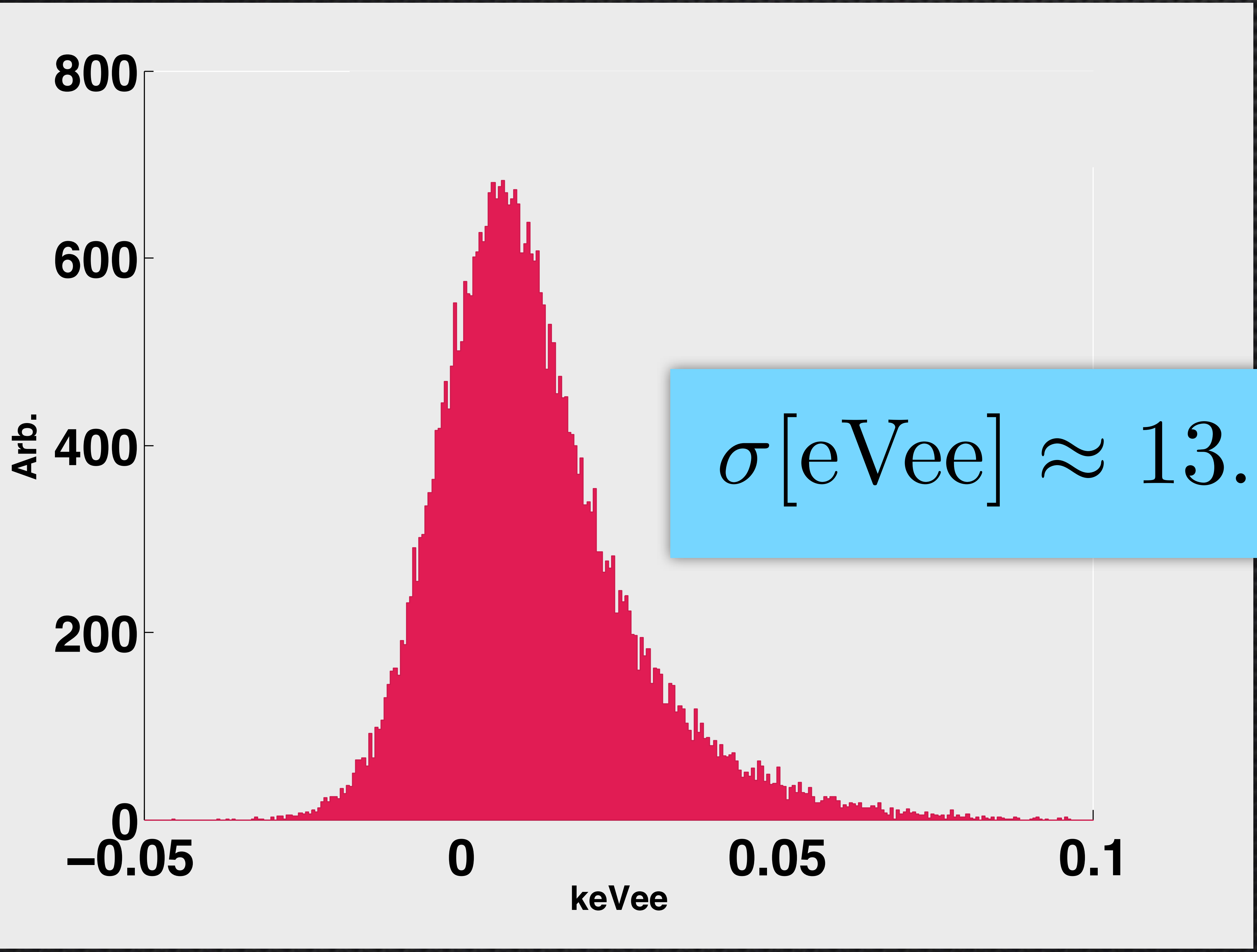


In electron equivalent units, spectral lines show sharp resolution demonstrating Luke gain

1.3 and 10.4 keV lines are seen with great resolution, 3.3 % and 1.9 % respectively.

Threshold

The RMS (σ) of base line noise indicates the smallest energy pulses we can detect.



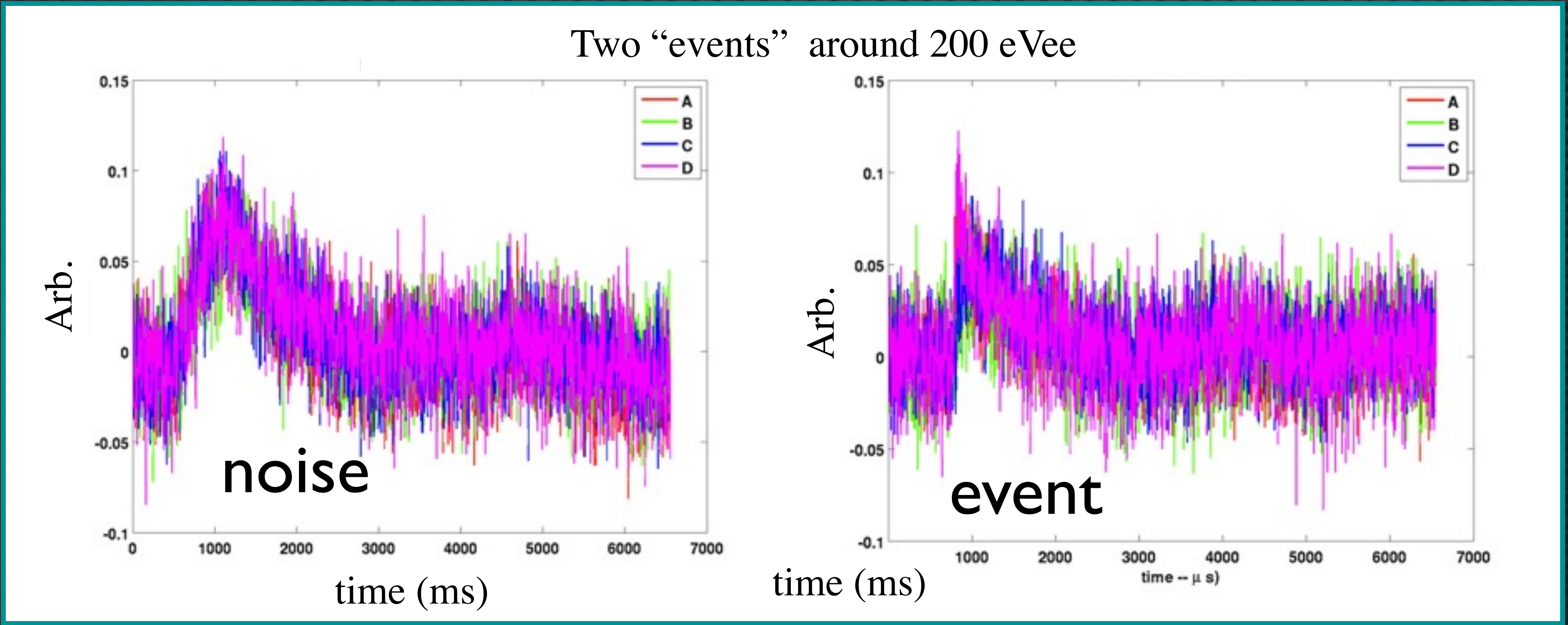
$$\sigma[\mathrm{eVee}] \approx 13.38\ \mathrm{eVee}$$

Current Status

Analysis is in final stage.

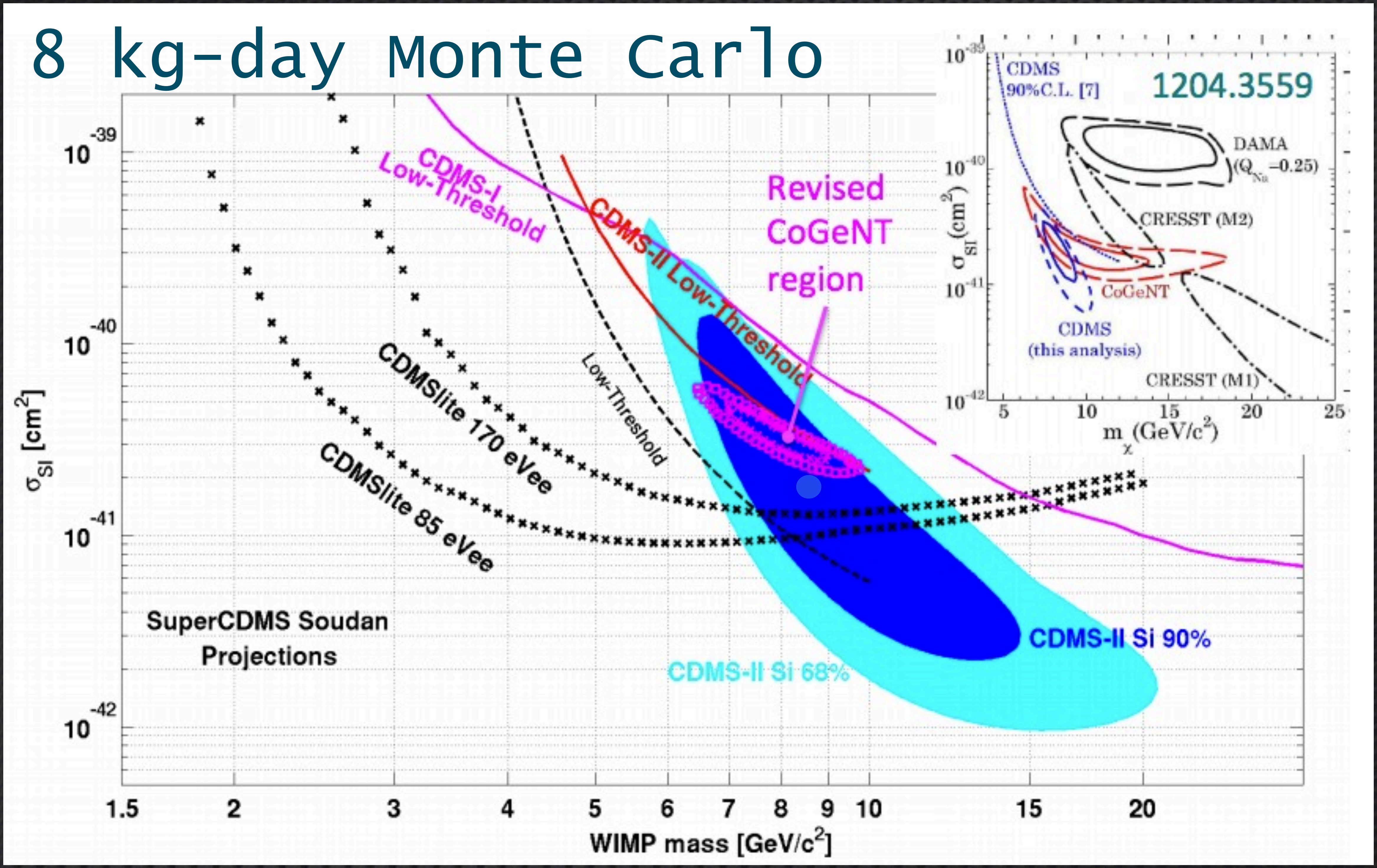
Checking various cut efficiencies.

Excess noise under 200 eVee



We are designing cuts against such noise.

Projected Low mass landscape



Conclusions

Si analysis

3 events in signal region at 140 kg-day exposure. Likelihood test favors WIMP+background at ~3σ

The maximum likelihood occurs at m_{WIMP} = 8.6 GeV/c^2 and σ_{SI} = 1.9x10-41 cm^2

CDMSlite

Novel method to lower ionization thresholds has been successfully tested.

Around 7 kg-days of data has been collected, and final analysis is underway.

Expect to reach ~170 eVee threshold, and provide strong commentary on Low mass WIMPS (O(10)GeV/c^2)

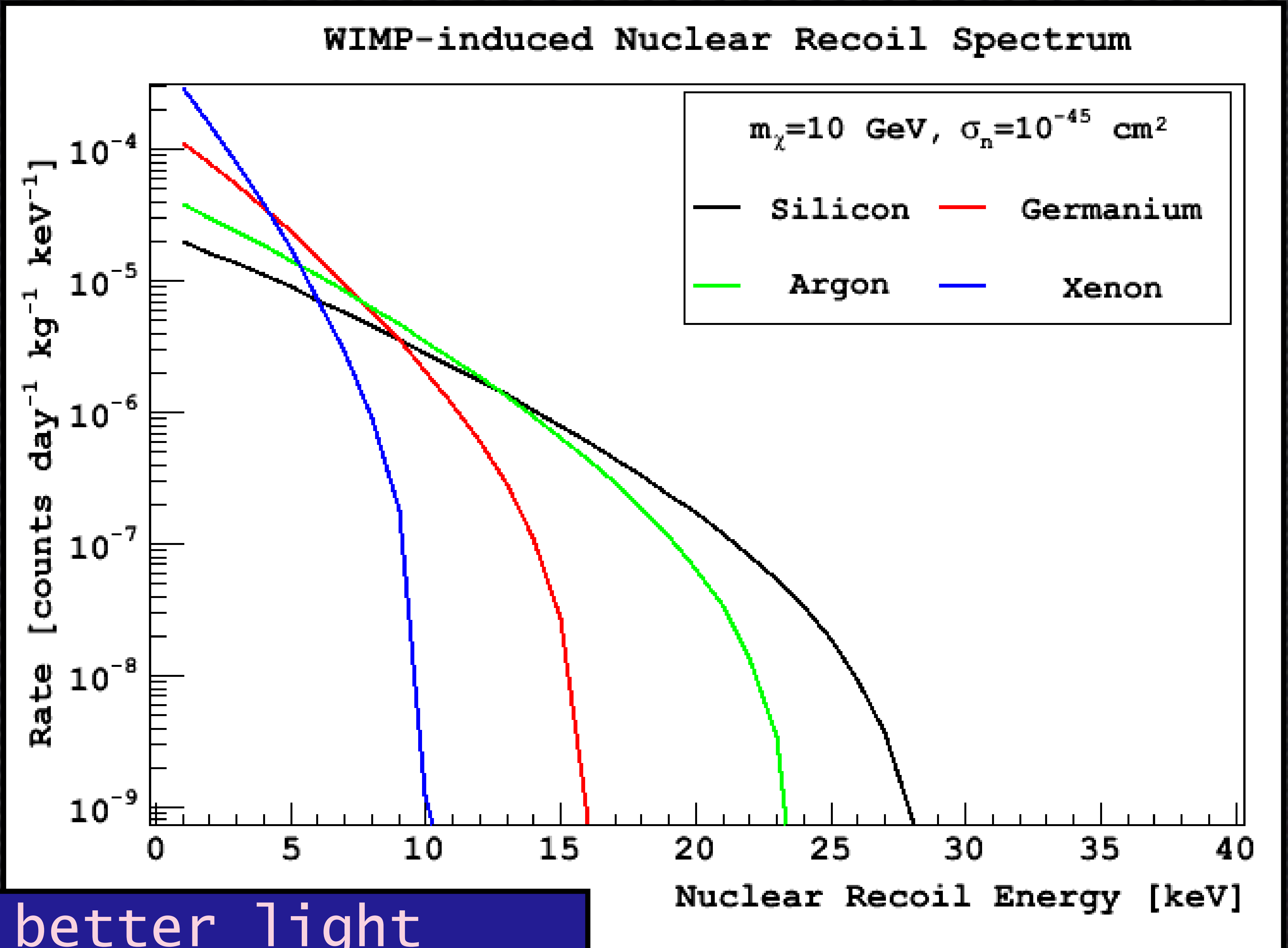
The SuperCDMS Collaboration

California Institute of Technology	Fermi National Accelerator Laboratory	Massachusetts Institute of Technology
Queen's University	Santa Clara University	SLAC / Kavli Institute for Particle Astrophysics and Cosmology
Southern Methodist University	Stanford University	Syracuse University
Texas A&M University	Universidad Autónoma de Madrid	University of British Columbia
University of California, Berkeley	Pacific Northwest National Laboratory	University of Colorado, Denver
University of Evansville	University of Florida	University of Minnesota

Thank you !

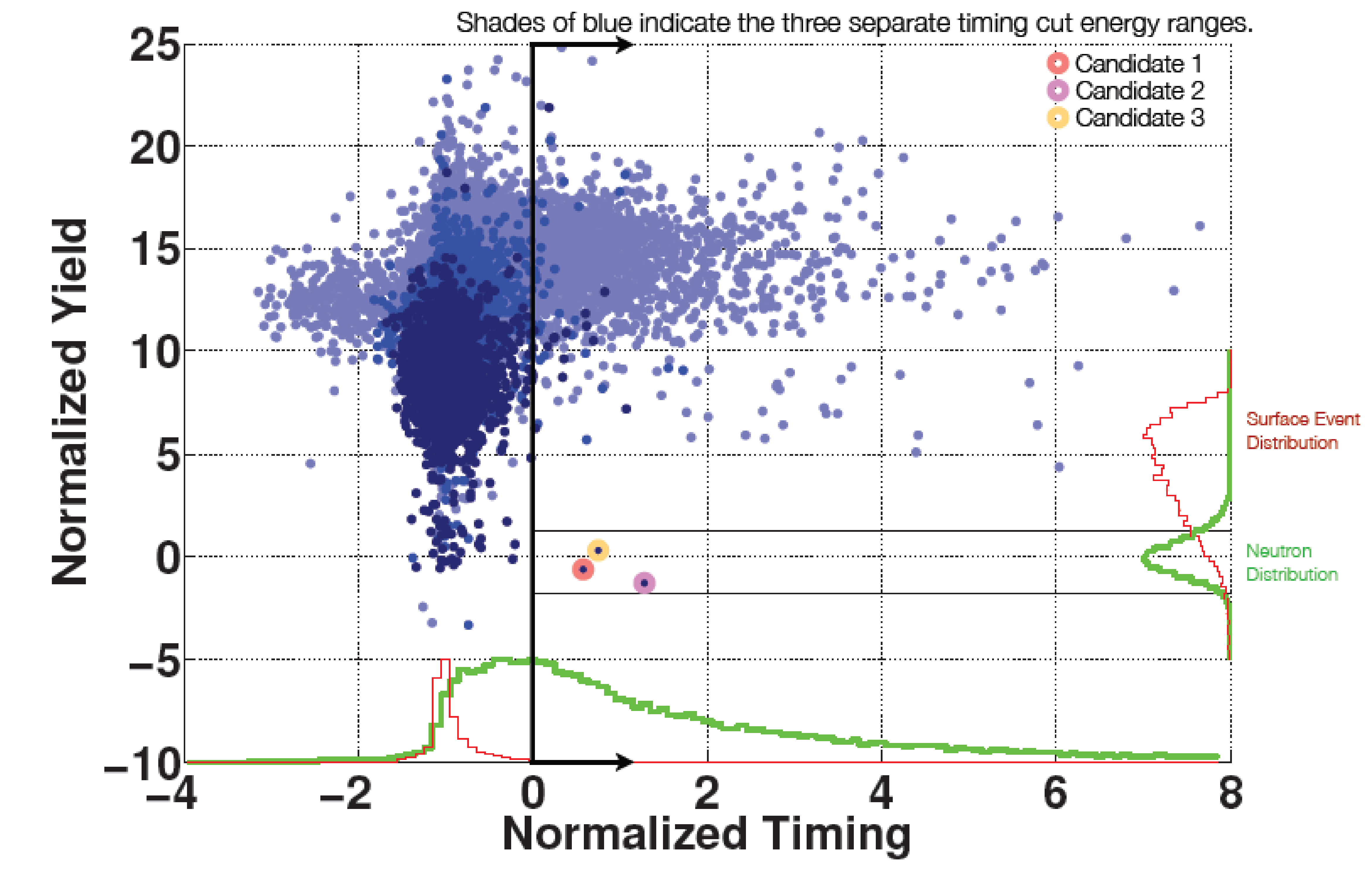
Some Back up (Si)

Expectations for Si detectors

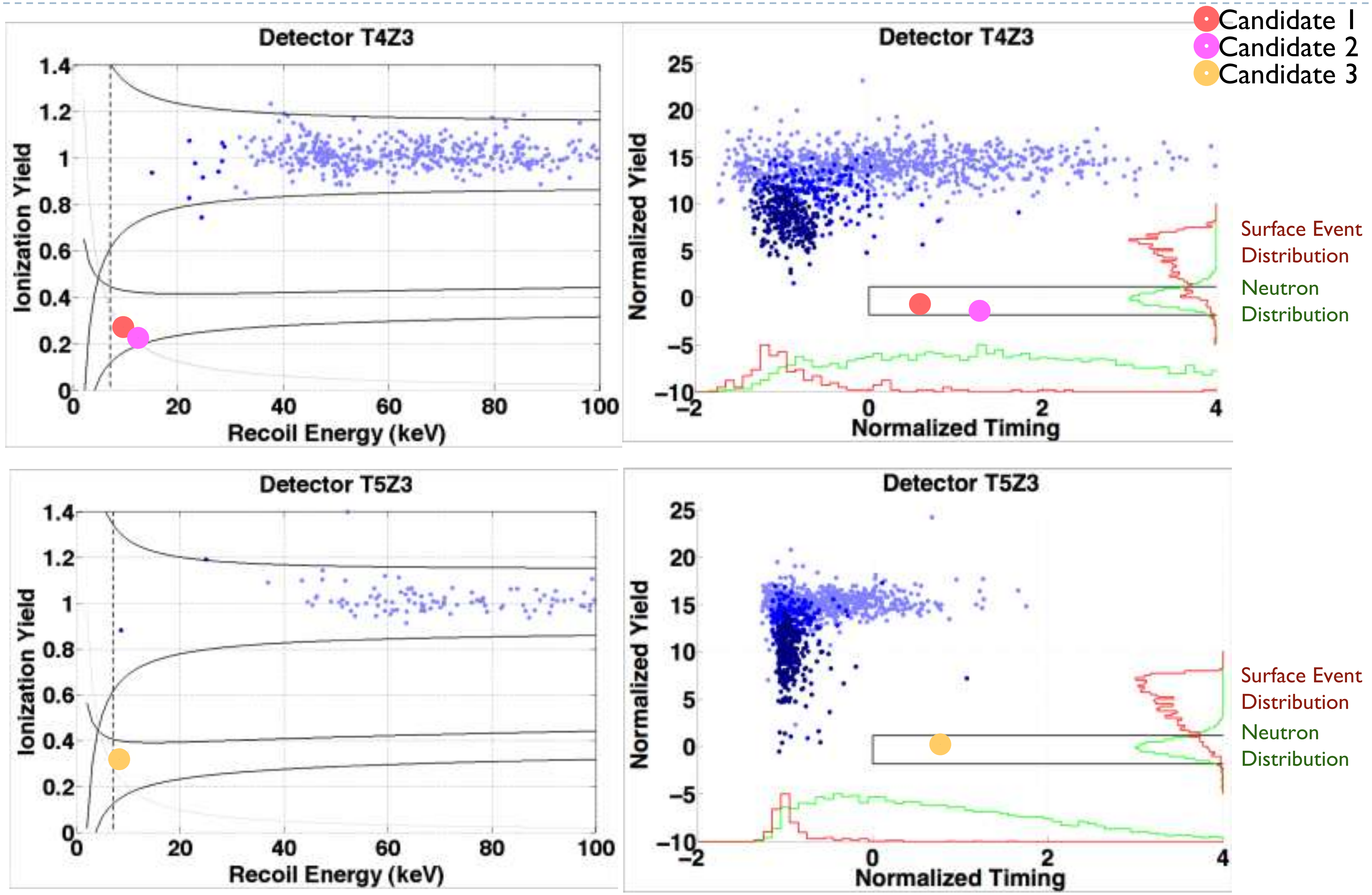


Si is a better light WIMP detector due to kinematic matching.

Results from the Si analysis

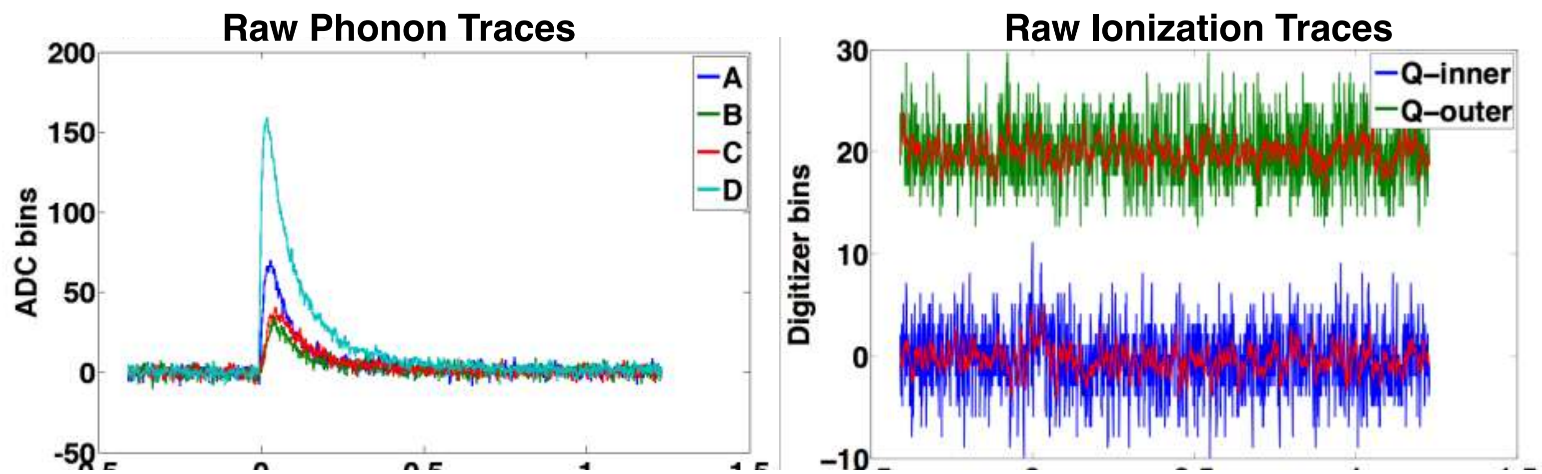


Three Events!

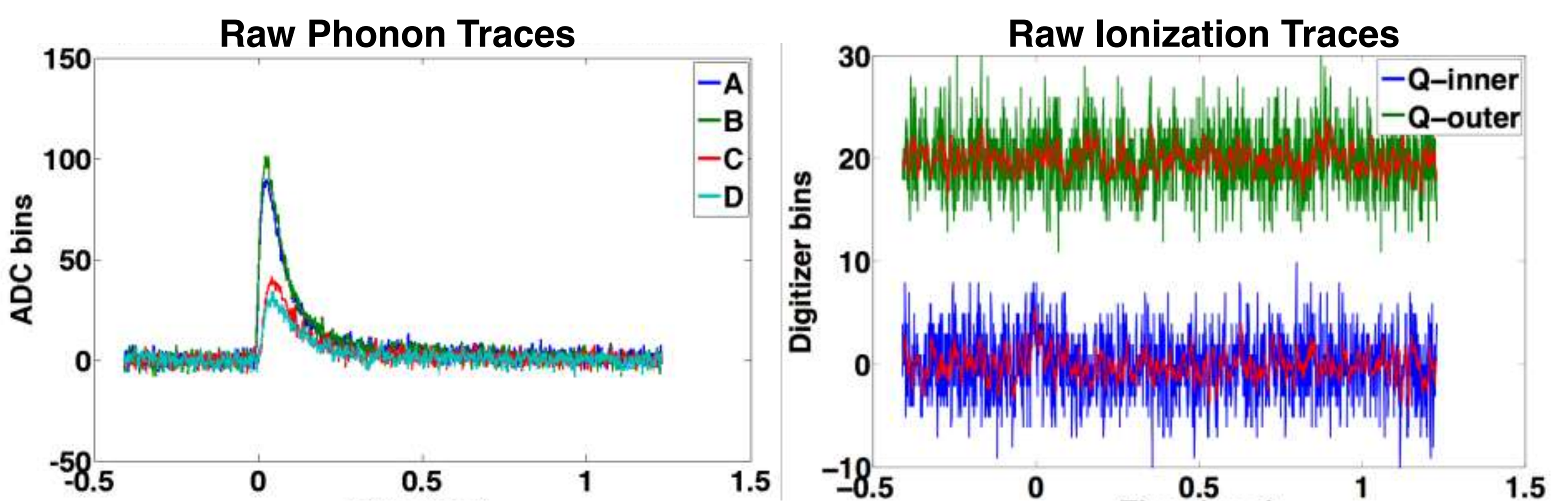


3 Events:

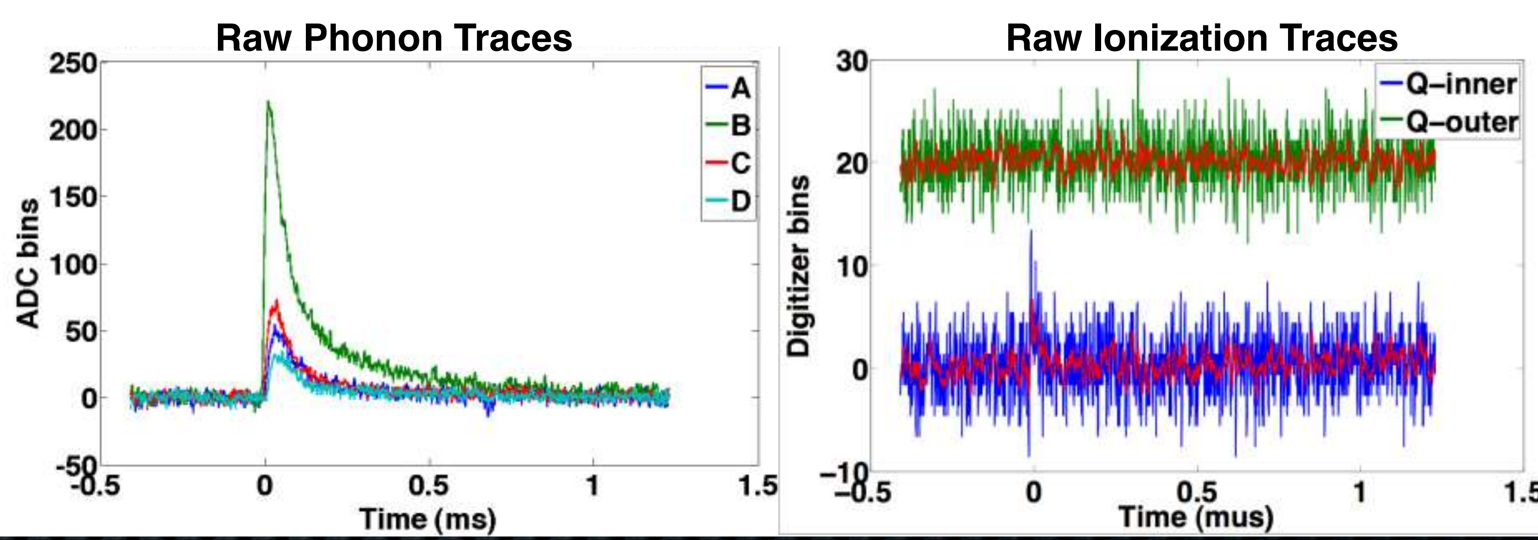
Candidate 1



Candidate 2



Candidate 3



Event Details

	Detector	Recoil Energy	Yield	Charge Signal to Noise	Date
Event 1	T4Z3	9.51 keV	0.27	4.87 σ	July 1, 2008
Event 2	T4Z3	12.29 keV	0.23	5.11 σ	Sep 6, 2008
Event 3	T5Z3	8.20 keV	0.32	6.66 σ	March 14, 2008

Post Unblinding checks

Events: occurred during stable periods, well reconstructed, not multiple scatters

Surface events

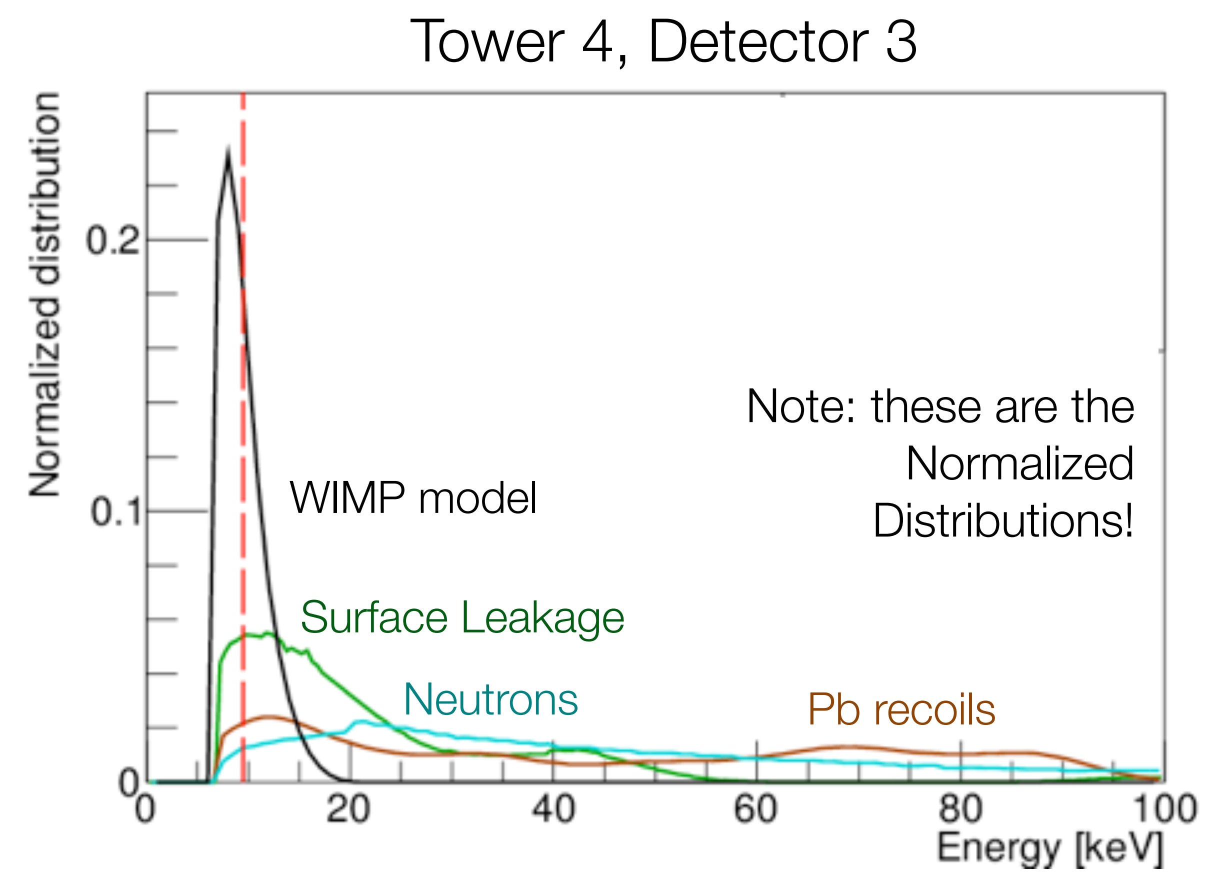
Using 3 NR sidebands, good estimates were obtained 0.41 (-.08 +.20 stat.) (-.24 +.28 syst.)

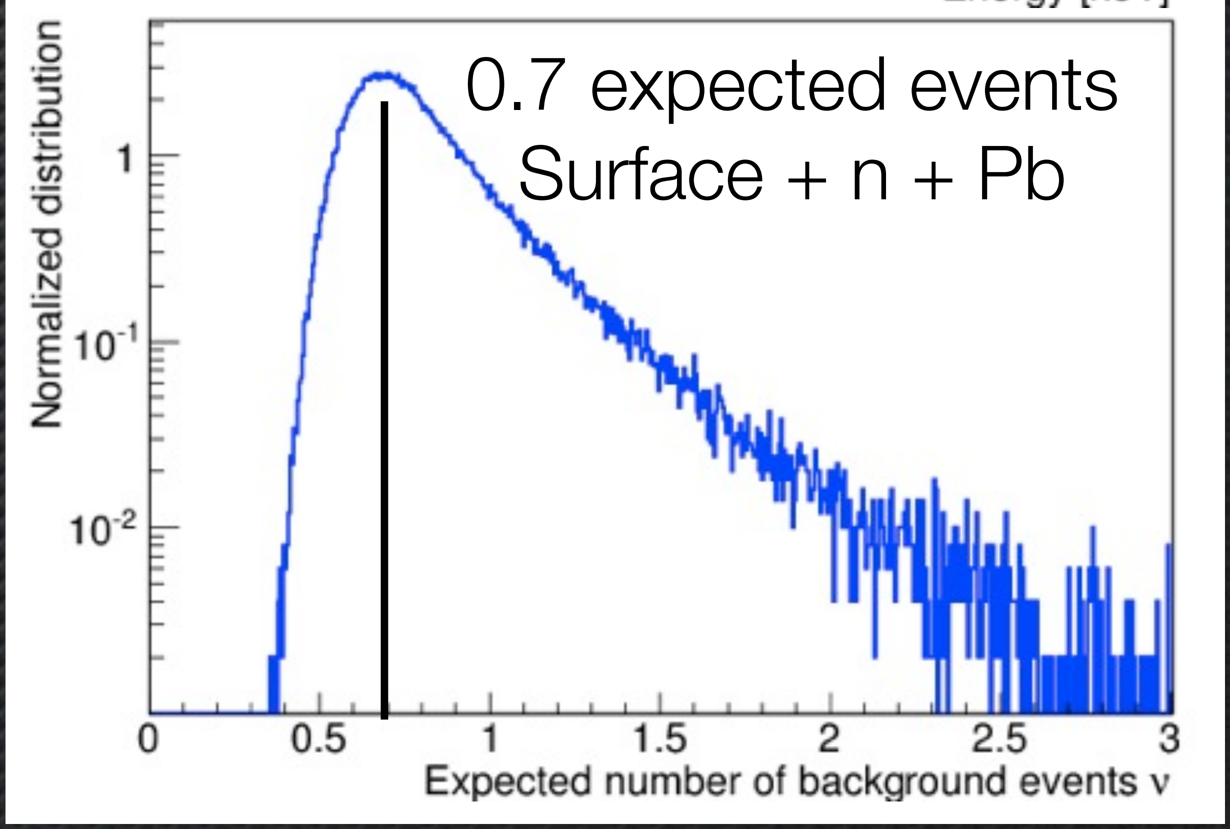
^{206}Pb recoil estimates limited to <0.08 events

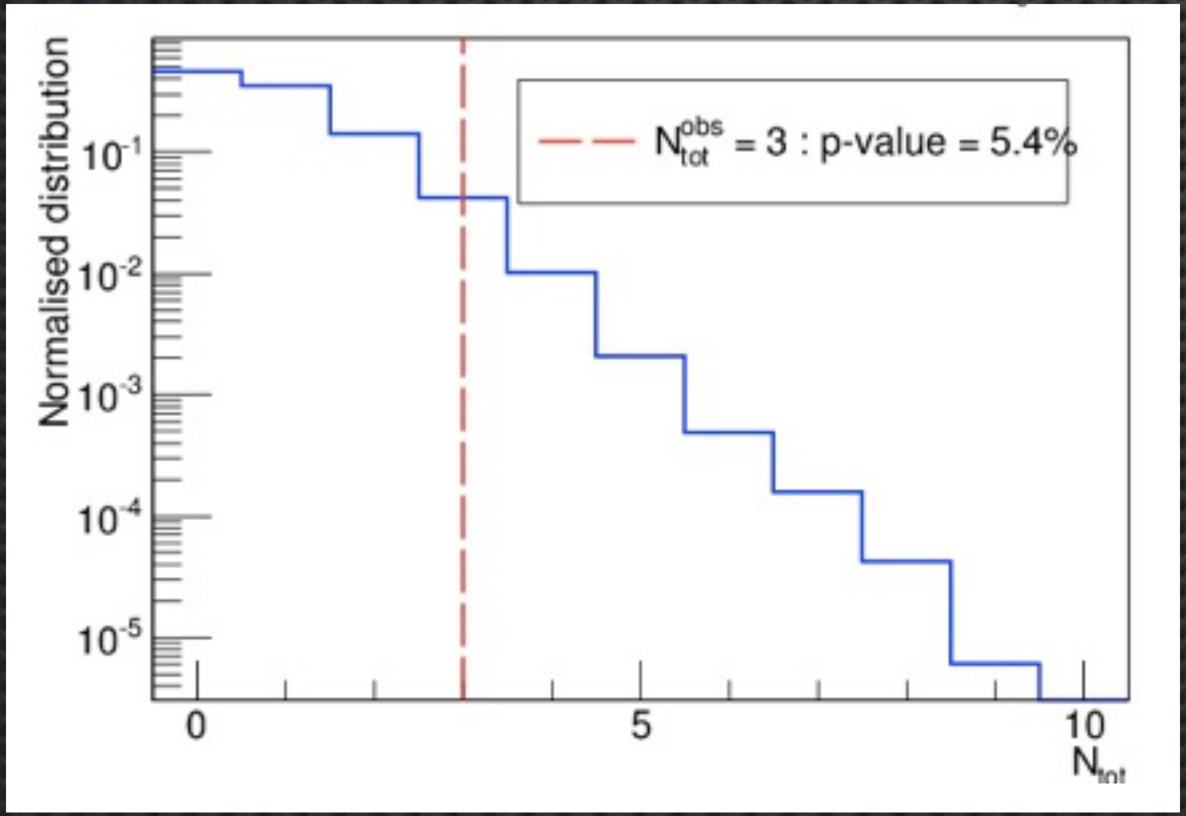
Likelihood analysis

Data driven background + WIMP hypothesis is tested by likelihood analysis

5.4% Probability of getting 3 event from Background only hypothesis.



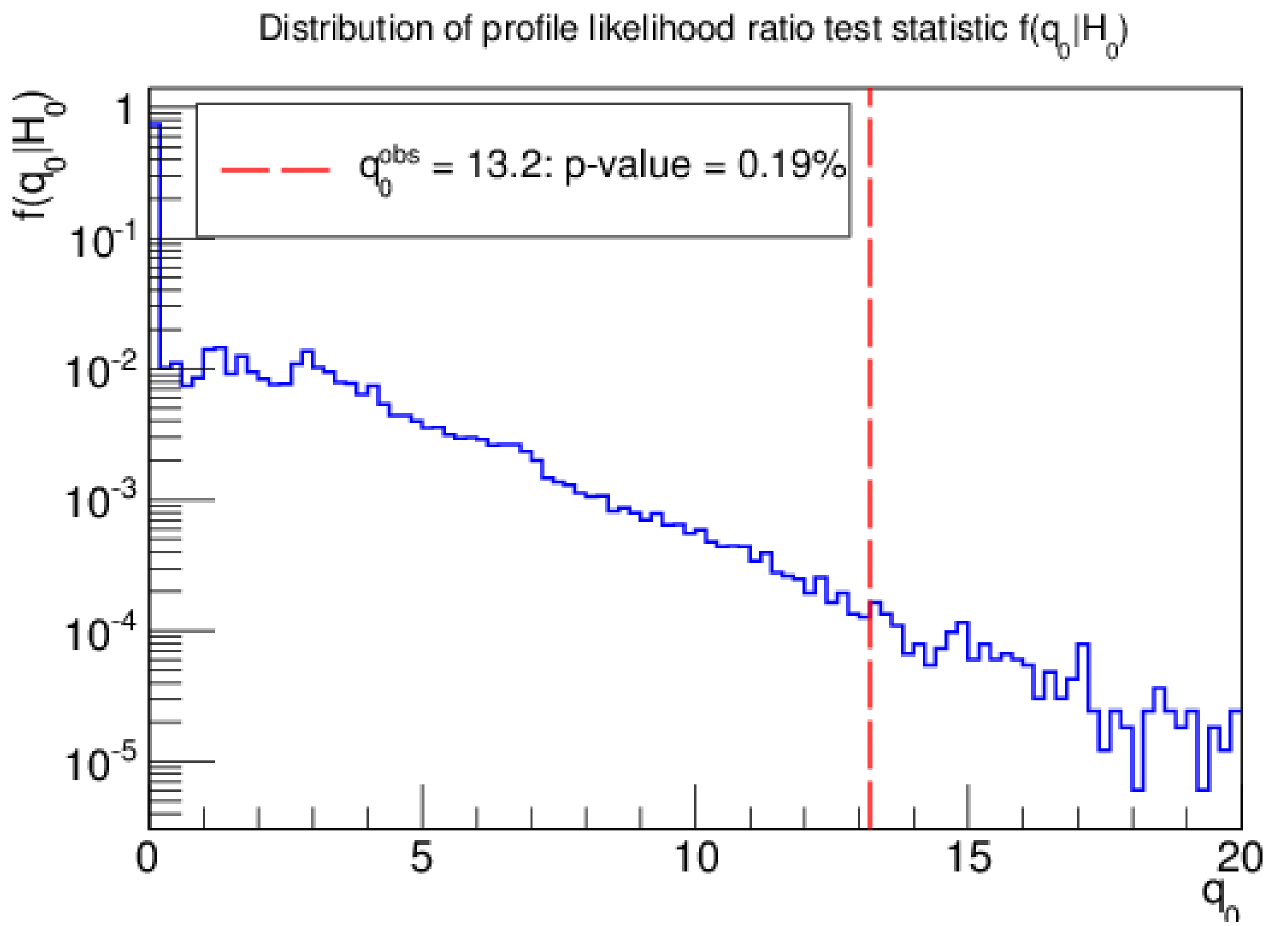




Testing our known background estimate against a WIMP+background hypothesis

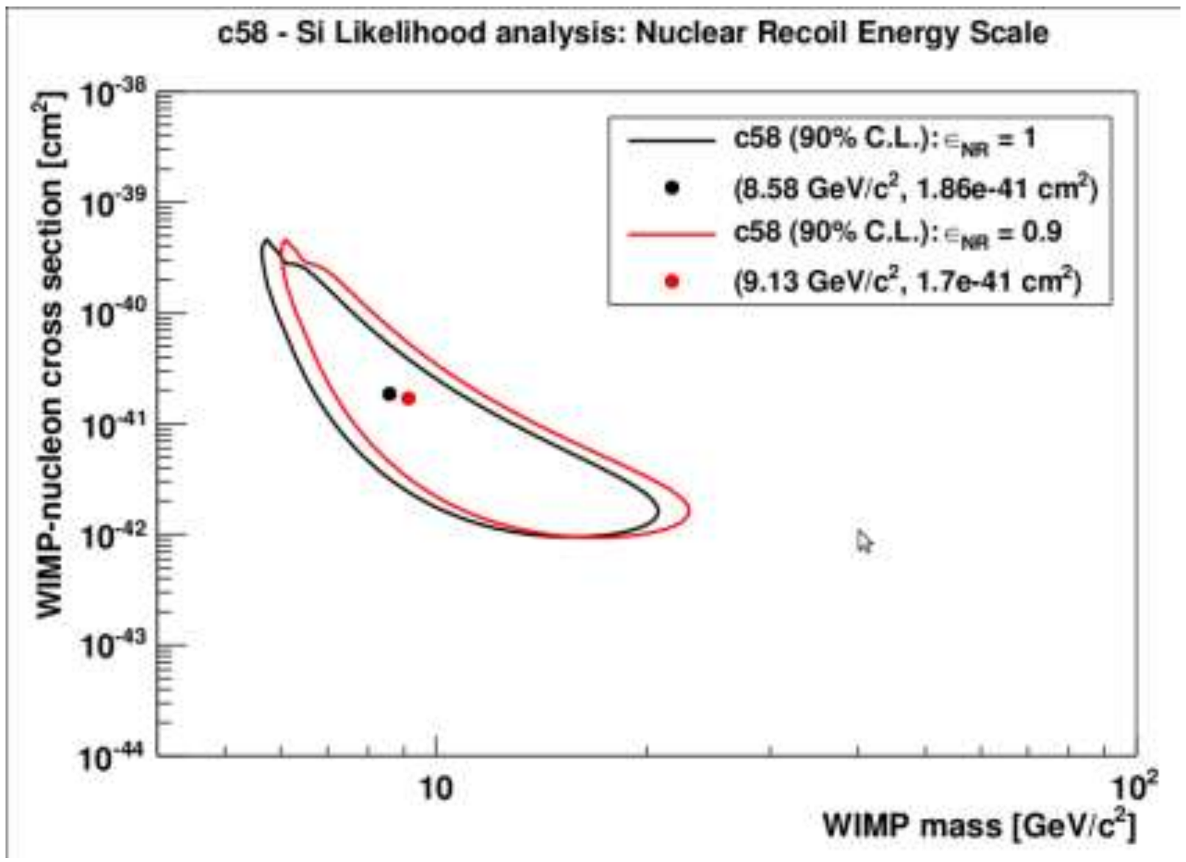
- A likelihood ratio test favors a WIMP+background hypothesis over the known background estimate as the source of our signal at the 99.81% confidence level (~3σ).
- The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c^2 and WIMP-nucleon cross section of 1.9×10^{-41} cm^2.

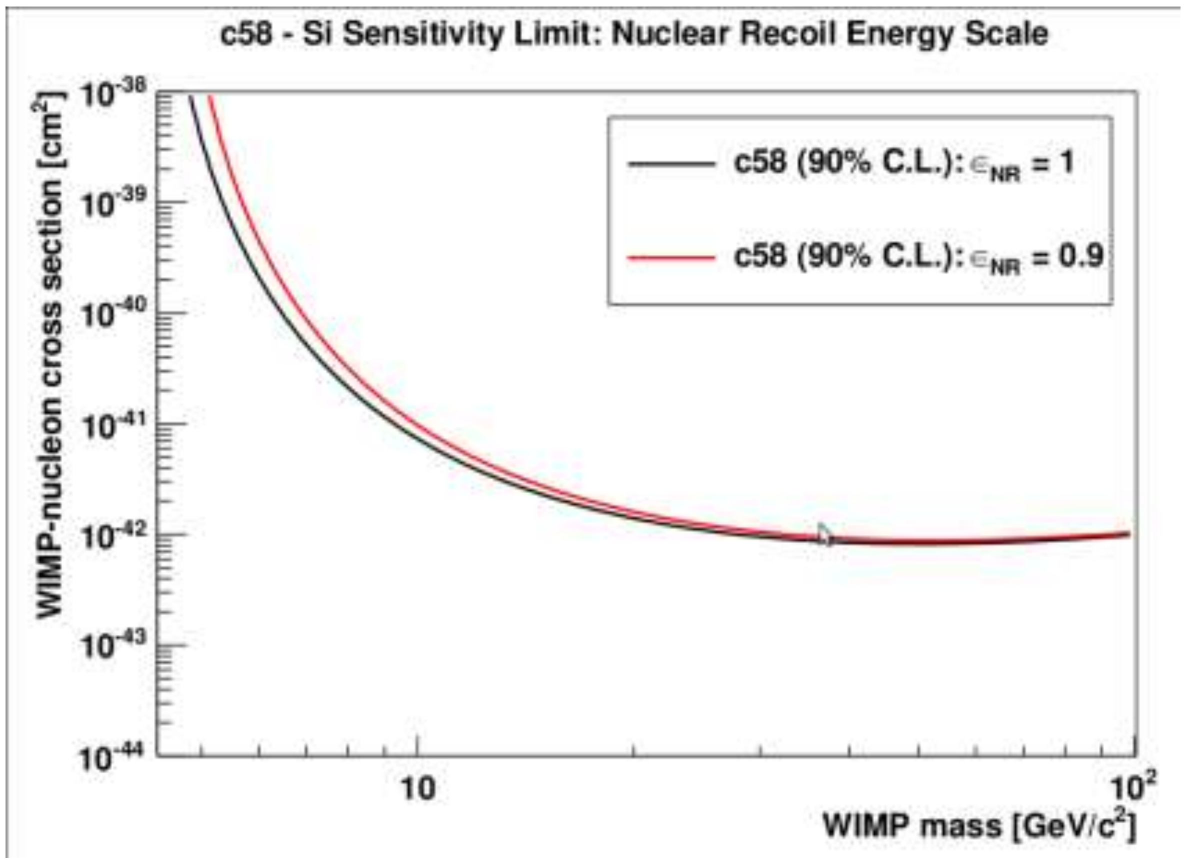
$$q_0 = -2\log\left\{\frac{\mathscr{L}(m_\chi, \sigma_{\chi-n}=0, \hat{\hat{\vec{\nu}}})}{\mathscr{L}(\hat{m}_\chi, \hat{\sigma}_{\chi-n}, \hat{\vec{\nu}})}\right\} \equiv 2\log\left\{\frac{\mathscr{L}(H_1)}{\mathscr{L}(H_0)}\right\}$$



Si nuclear recoil energy scale

- Possible ~10% underestimation of Si nuclear recoil energy scale
- Below 20 GeV/c2 the change is well approximated by shifting the limits parallel to the mass axis by ~7%. In addition, neutron calibration multiple scattering effects improve the response to WIMPs by shifting the upper limit down parallel to the cross-section axis by ~5%.





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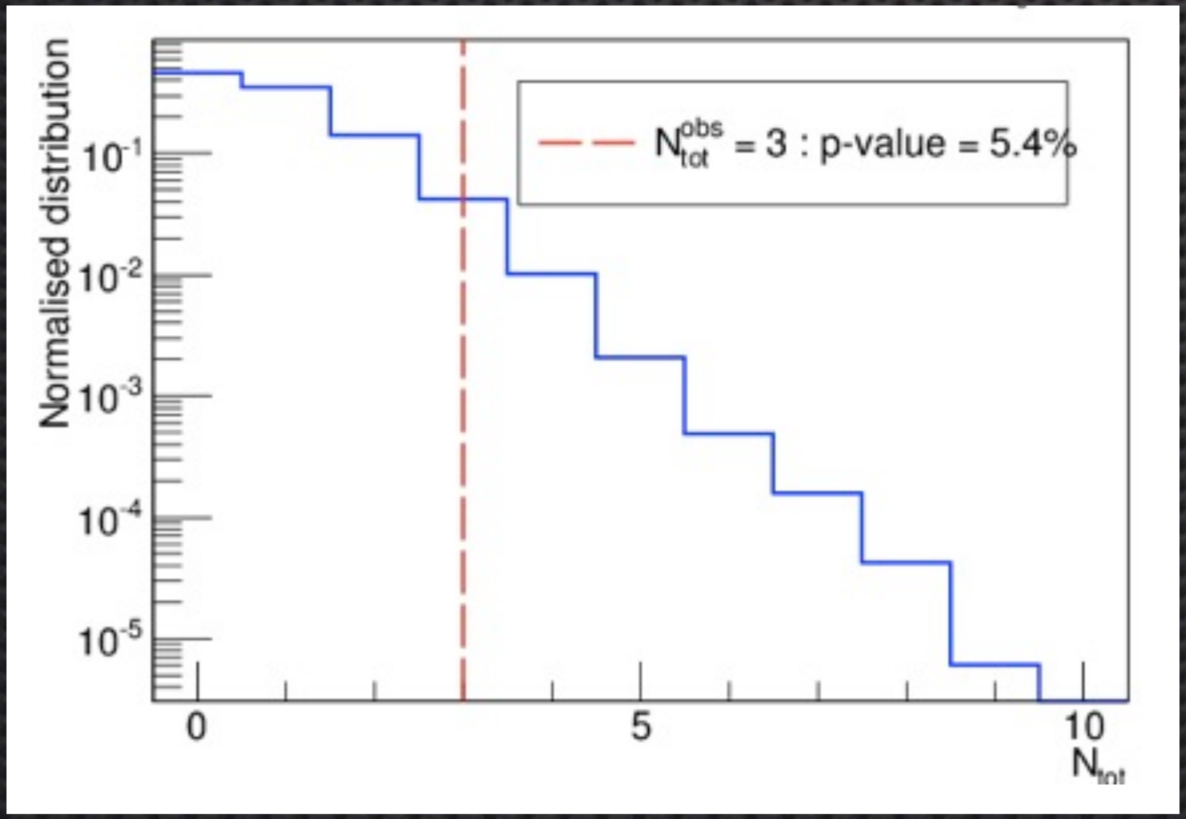
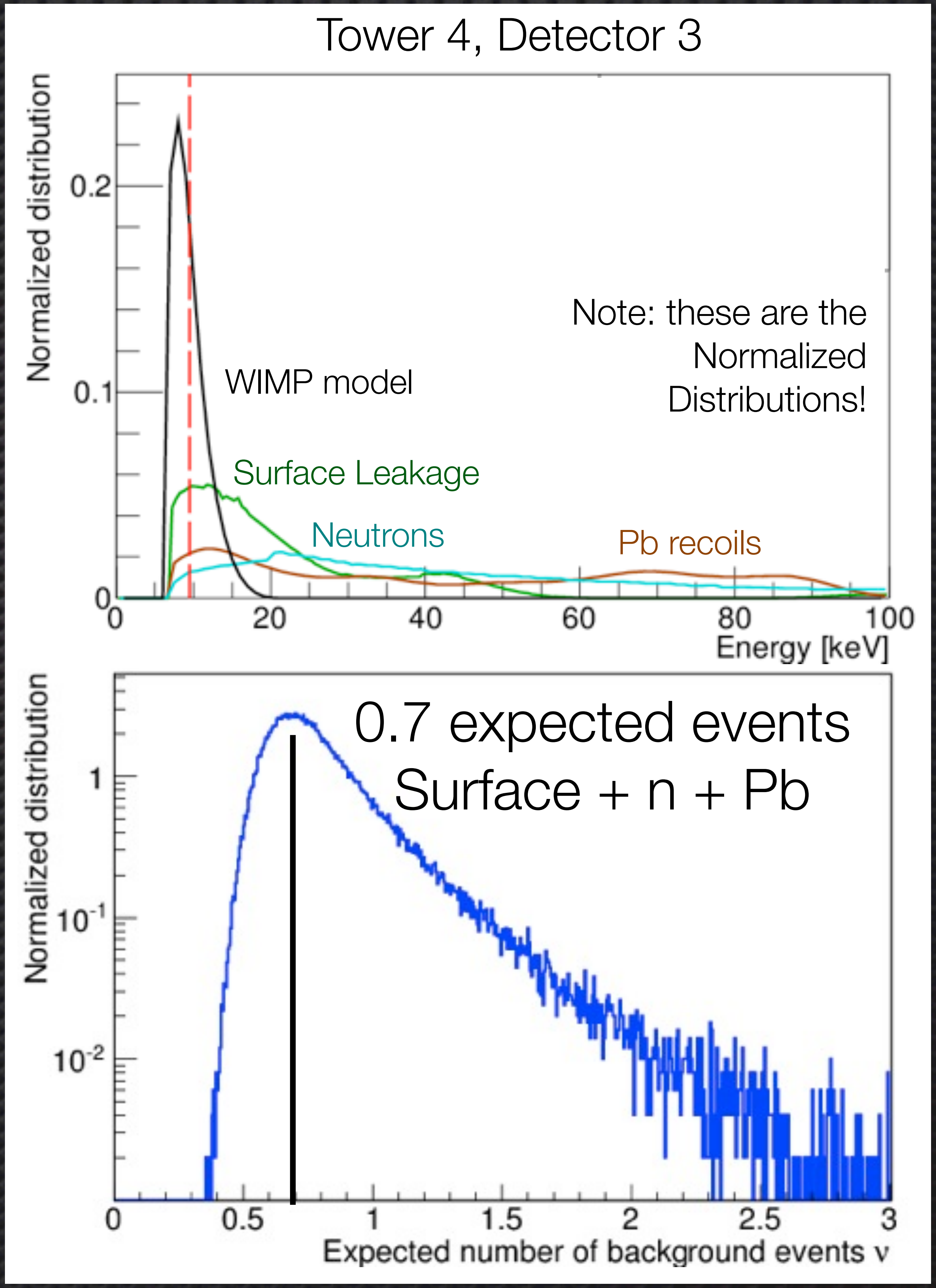




Interpretation of 3 candidates

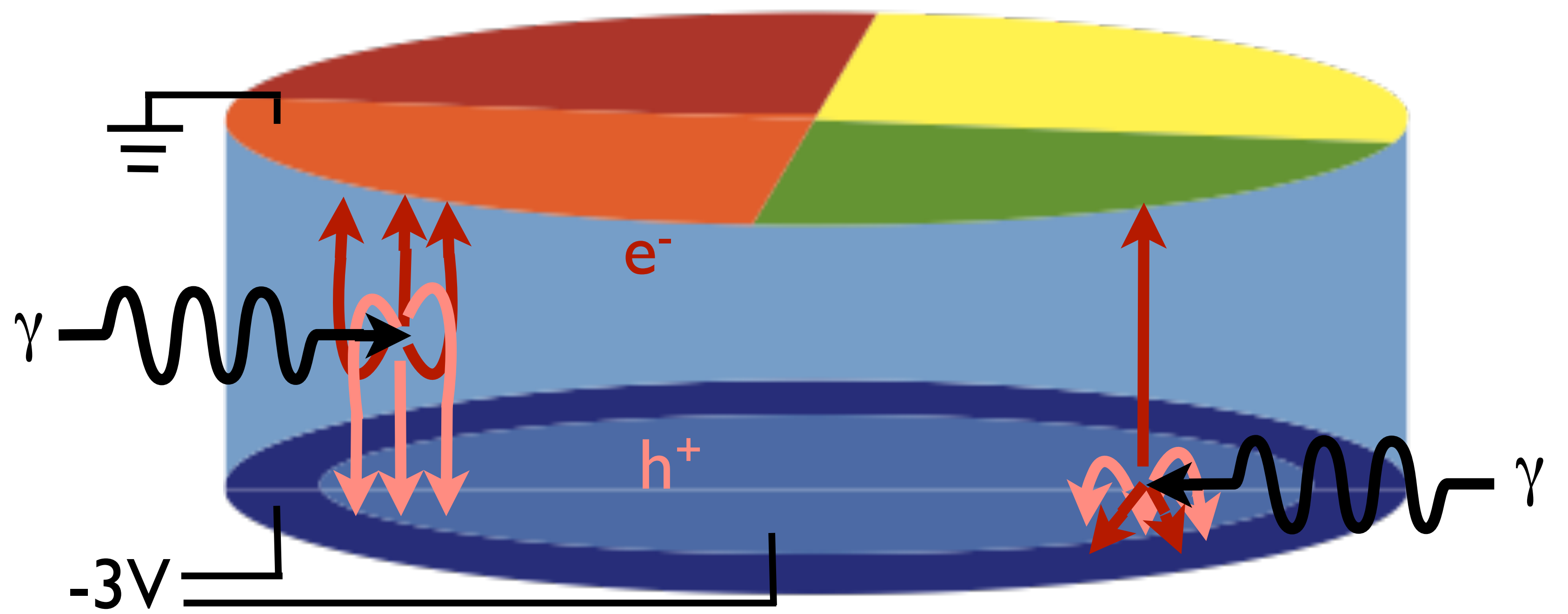
A likelihood ratio test favors WIMP+background* hypothesis over the known background estimate as the source of these events at the 99.81% CL(~3σ).

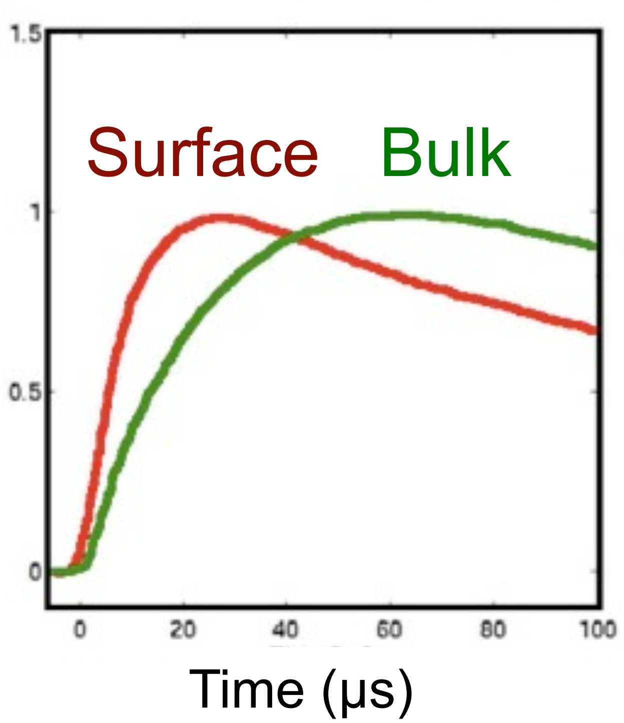
The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c^2 and WIMP-nucleon cross section of 1.9x10-41 cm^2

* for background, data driven pdfs of surface leakage (0.41 measured), neutrons (<0.13) and Pb recoils (<0.08) were used. Zero charge leakage estimates were small and were not factored in.

CDMS II : Surface Events

Phonon pulse shape tags surface events





1:200 rejection at ~50% neutron acceptance